CT scanning strategy – Prediction of image quality

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Application of CT Scanning in Industry

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1. The problem: How to scan an workpiece?
2. Analysing the problem
3. Model of contrast transfer properties
4. Model of large signal-to-noise ratio
5. A process chain for resolution-to-noise optimization
6. Outlook to future work

The problem: How to scan a workpiece?

Source: Zeiss IMT

- Wide range of workpieces
- Differences in
  - Size
  - Form
  - Material
- No standardized approach for scanning
- <u>High user influence</u>

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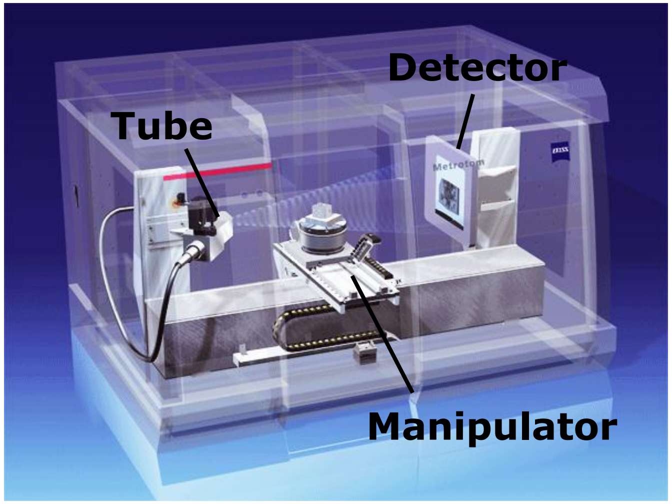
Typical scanning parameters and side conditions



Source: Zeiss IMT

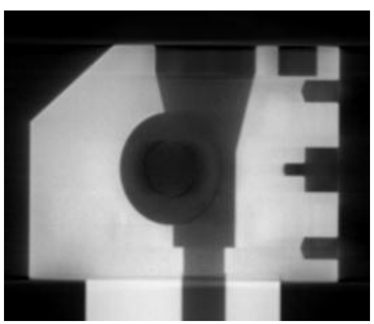
System component	Parameter
X-ray tube	Voltage Current Prefiltering
Flat-panel detector	Integration time Number of image averaging Pixel binning
Manipulator system	Source-to-object distance (SOD) Number of projections (views)

Typical side conditions (system limits):

- Orientation of the workpiece on the rotary table
- Focal spot size to tube power relation
- Detector resolution
- Detector sensitivity
- Available scanning time

From image quality to measurand

CT	Image processing	Coordinate measurement	Measurand
Reconstruction image quality	**Surface extraction**	**Coordinate measurement in 3D model**	**Determination of dimension, form, and position**



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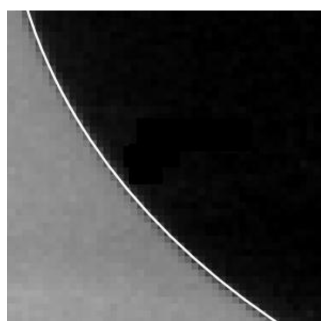

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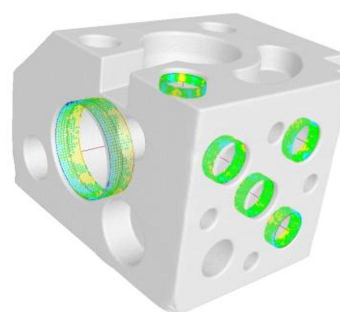
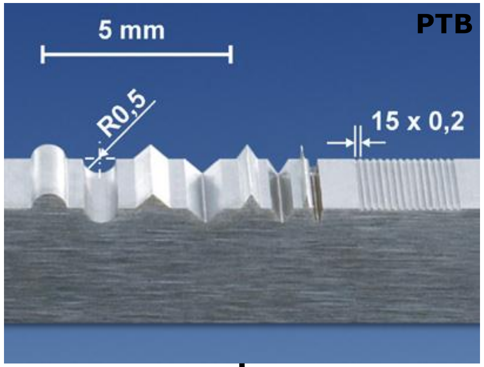
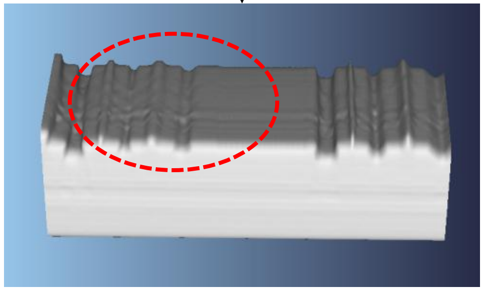
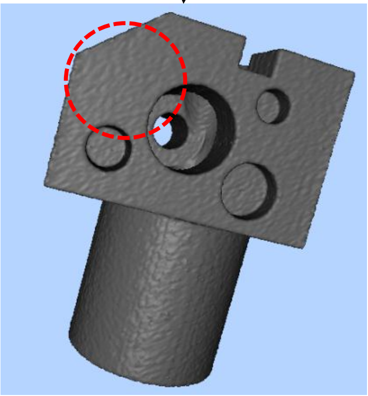


→

Ø = 15,5 mm

L = 32,8 mm

Image quality in terms of resolution and noise

	Resolution	Noise
Object		
CT		

Depending on object, scanning parameters, side conditions (system limits)

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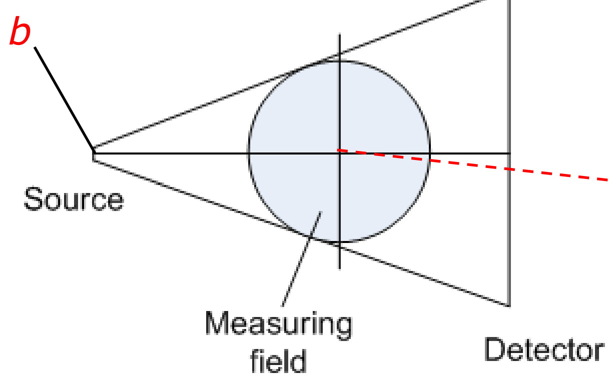
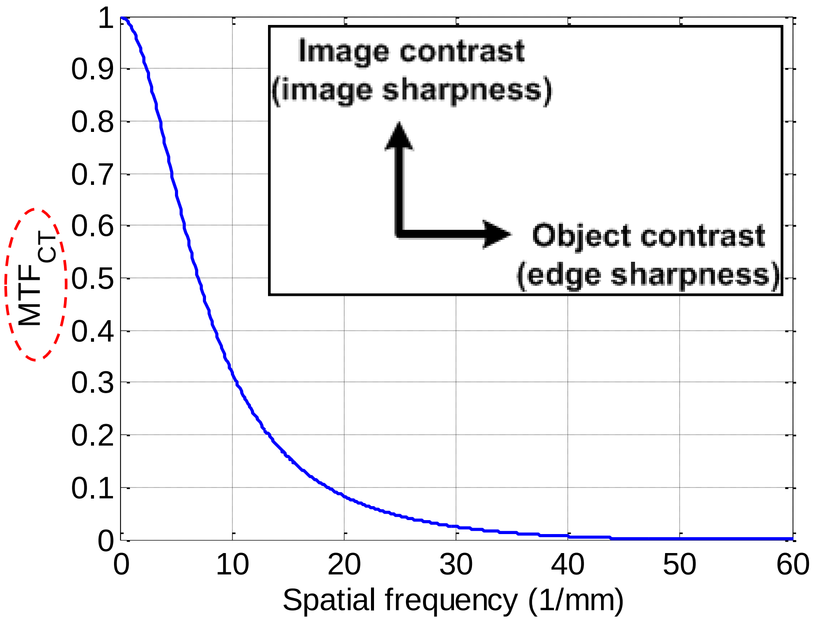
Model of contrast transfer properties



$$m = \frac{\mathrm{SDD}}{\mathrm{SOD}}$$



$$\mathrm{MTF}_{CT}(u) = \mathrm{MTF}_{FS}(u) \times \mathrm{MTF}_{Pix}(u) \times \mathrm{MTF}_{Det}(u) \times \mathrm{MTF}_{Reco}(u) \times \mathrm{MTF}_{Vox}(u) = f(m)$$

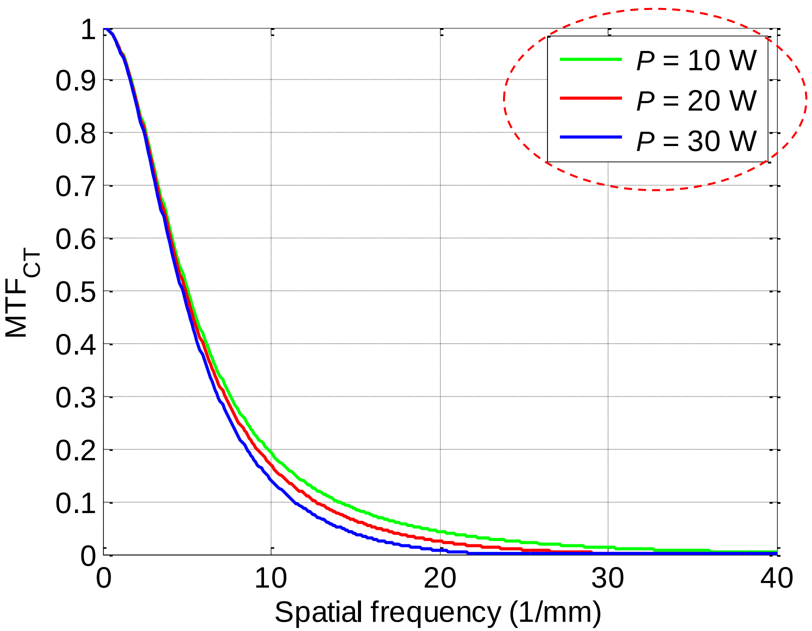
$\mathrm{sinc}(b \cdot (m-1) \cdot u/m)$ → $b = f(P)$ → $b \approx 1\ldots2$ µm per W

Model of contrast transfer properties

Example:

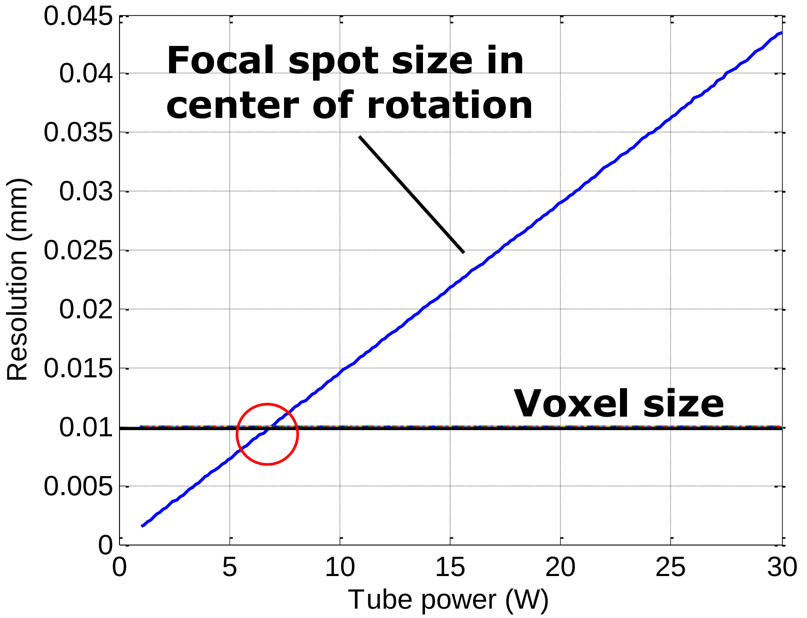
- *b* = 1,5 µm per W
- *m* = 20
- Detector matrix : 2048 x 2048
- Scintillator type : Lanex fine
- Pixel size = 0,2 mm (no binning)

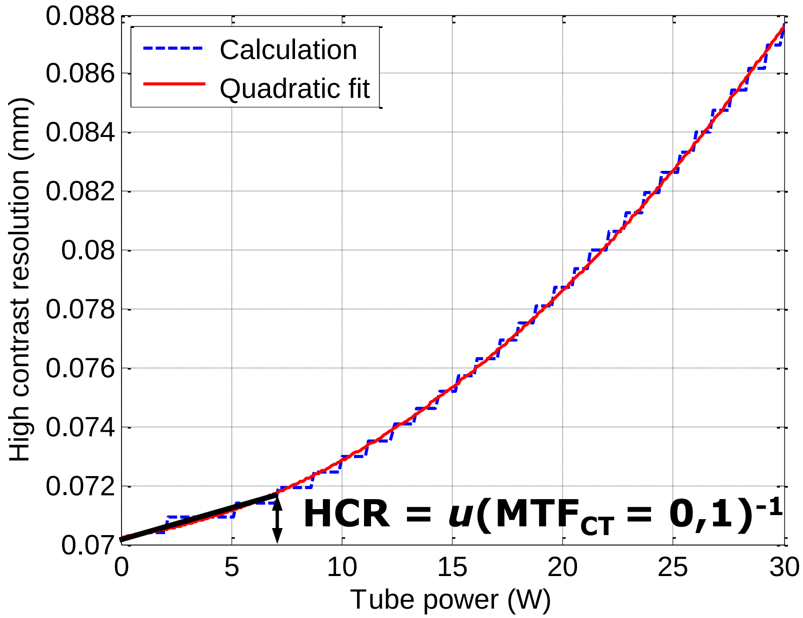
→ Voxel size = 10 µm



What could be a limiting factor for the tube power?

Model of contrast transfer properties





Simple criteria:

Focal spot size ≤ Voxel size

HCR decreases quadratically with tube power (focal spot size)!

here → P_{max} = 7 W

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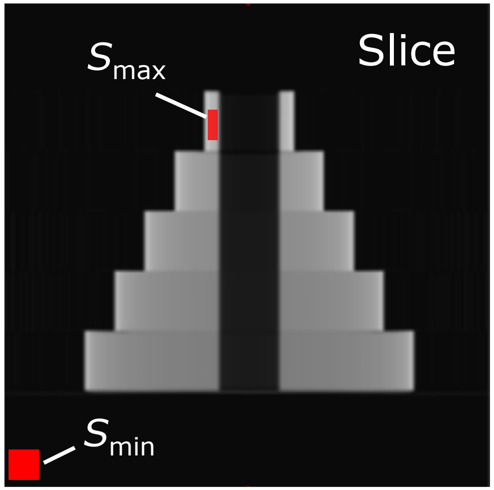
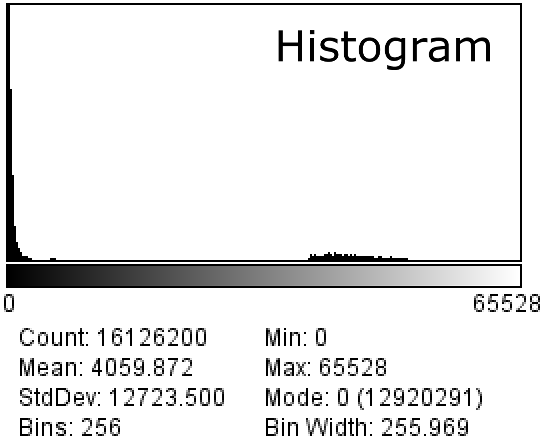
Model of large signal-to noise ratio

A) Voxel volume





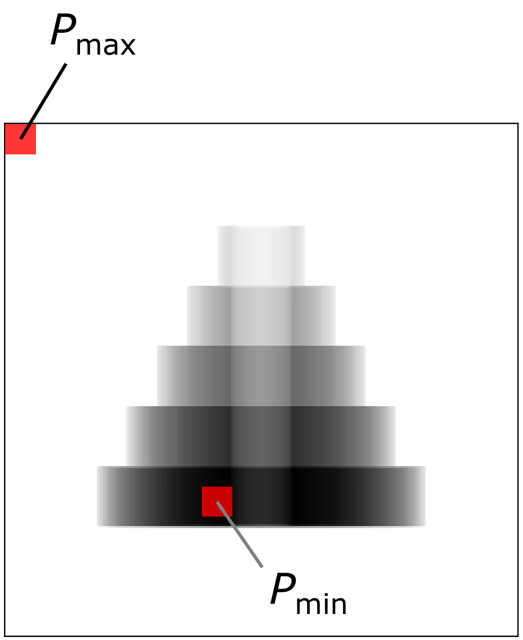
$$\mathrm{SNR}_{\mathrm{CT}} = \frac{\Delta S}{\sigma_{\Delta S}} = \frac{\mathrm{E}[S_{\mathrm{max}}] - \mathrm{E}[S_{\mathrm{min}}]}{\sqrt{\sigma^2[S_{\mathrm{max}}] - \sigma^2[S_{\mathrm{min}}]}}$$

*Voxel value **S** is proportional to the effective linear attenuation coefficient*

How to maximize $\mathrm{SNR}_{\mathrm{CT}}$?

Model of large signal-to noise ratio

B) Attenuation coefficient and projection signal



Projection image

Number of views

$$\mathrm{SNR_{CT}} \approx \frac{M}{c_{\mathrm{conv}} \cdot c} \cdot \mathrm{SNR_{coef}}$$

Influence of image filtering

($\mathrm{MTF_{CT}}$)

$$\mathrm{SNR_{coef}} = \frac{|\ln(\mathrm{E}[P_{\mathrm{max}}]) - \ln(\mathrm{E}[P_{\mathrm{min}}])|}{\sigma_{\mathrm{coef}}}$$

$$\sigma_{\mathrm{coef}} = M \cdot \left[-\ln\left(\frac{P_{\mathrm{min}}}{P_{\mathrm{max}}}\right)\right] \approx \frac{\sigma^2[P_{\mathrm{max}}]}{\mathrm{E}[P_{\mathrm{max}}]^2} + \frac{\sigma^2[P_{\mathrm{min}}]}{\mathrm{E}[P_{\mathrm{min}}]^2}$$

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A process chain for resolution-to-noise optimization

- **Select type of prefilter depending of the object (material, size, form)**
- **Place the object onto the rotary table (minimize radiographic lengths)**
- **Adjust magnification**
- **Maximum available scanning time?** → $t_{tot} \approx M \cdot (t_{int} \cdot n_{av} + t_{rot} + t_{skip}) - t_{rot} - t_{skip}$

M ≈ Size of detector matrix

↓ ***m*, voxel size**

Determination of maximum tube power

(Resolution) → Calculation

↓ $P_{max} = U \cdot I$

Determination of tube voltage and current for a maximum SNR_{CT}

(Noise) → Empirical (calculation)

Content

Outlook to future work

- Analysing of the resolution properties at the edge of the measuring field
- Development of a metric to quantify the locally forming of image artefacts in the reconstructed volume
- Testing the proposed process chain using measurement data. Results will be published soon!

Thank you very much for your attention!