Uncertainty of Dimensional Measurements using Computed Tomography

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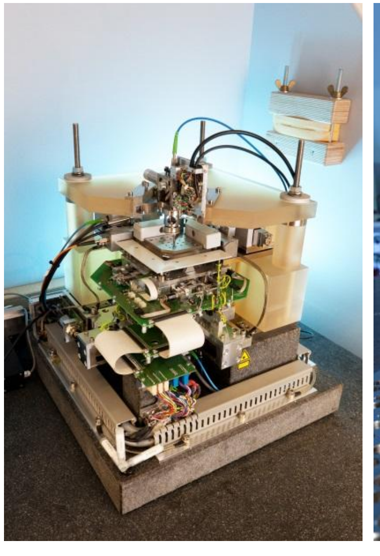
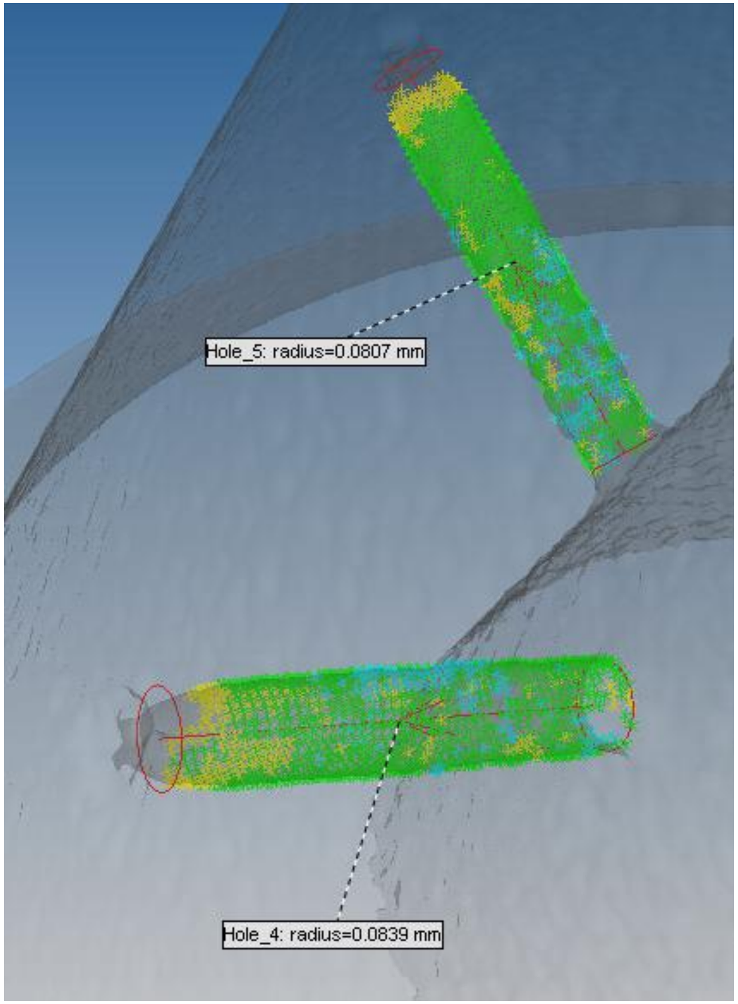
Institute of Manufacturing Metrology

XCT-Seminar | Munich, 8th of December 2014



X-ray CT - dimensional measurements

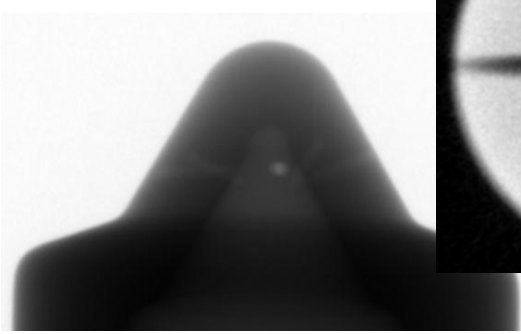
micro XCT of an injection nozzle
radius of an injection hole approx. 80 µm



X-ray CT - dimensional measurements

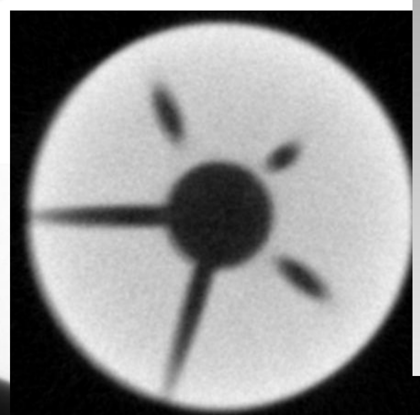
Process of a dimensional XCT measurement….

acquisition of 2-D projections



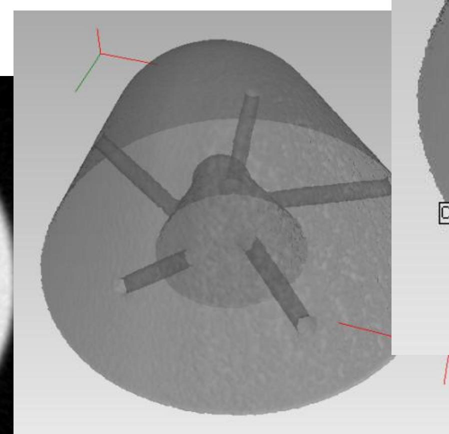
X-ray absorption along path between spot and detector pixel

reconstruction of 3-D volume



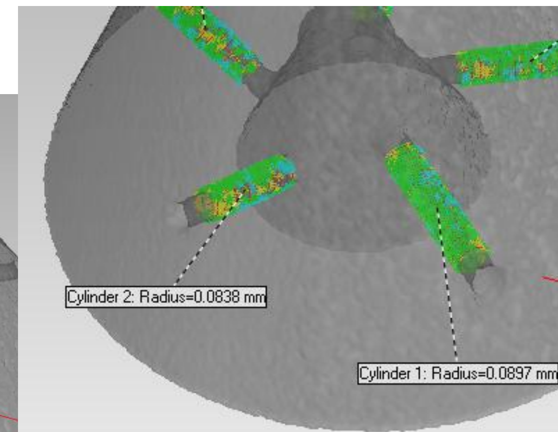
mean X-ray absorption coefficient within a voxel

surface extraction



coordinates of surface points

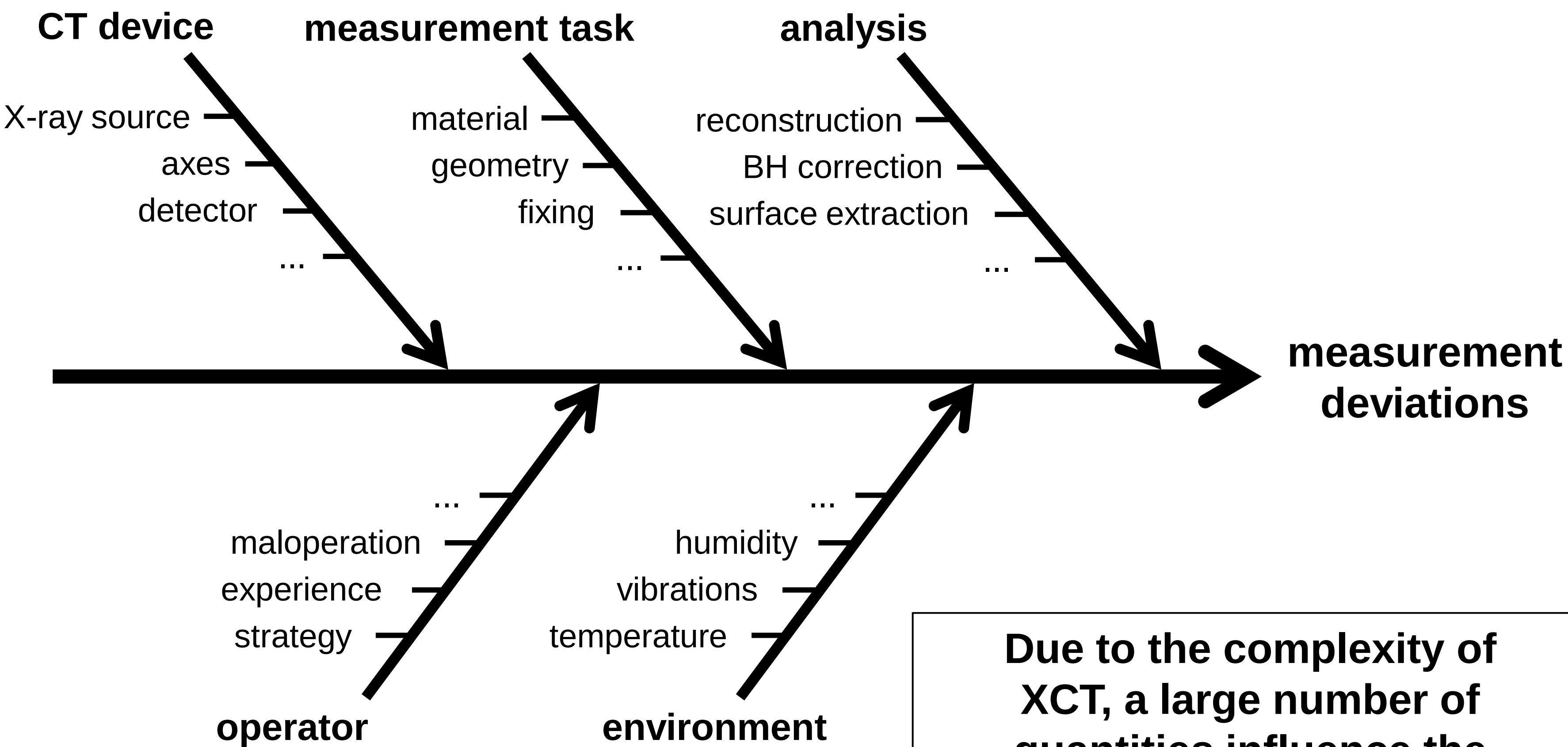
dimensional measurement



dimensional measurement (size, form, position)

… and the quantities that are actually measured.

X-ray CT - dimensional measurements

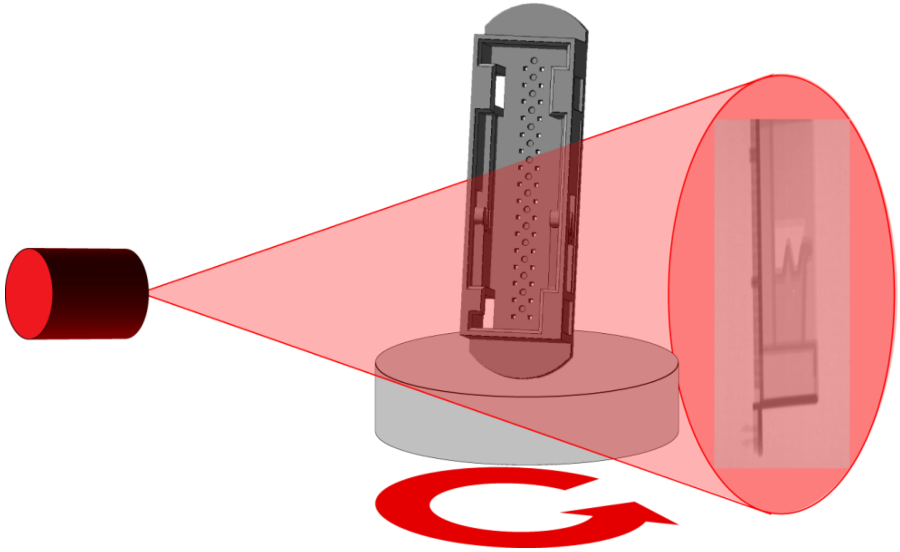


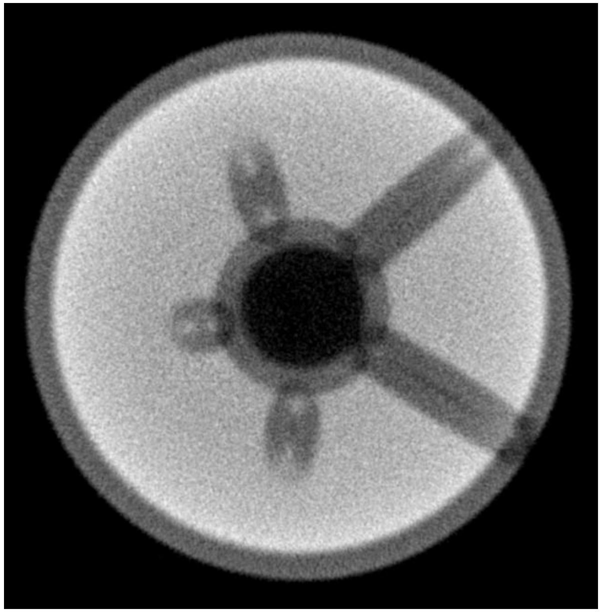
Due to the complexity of XCT, a large number of quantities influence the result of an XCT measurement.

Examples of error sources

Similarly to traditional tactile CMMs, a precise kinematic system is required for precise measurement results. If incorrect geometric parameters are used as input for reconstruction, artifacts in the volume data may occur.

In contrast to the example depicted here, usually these artifacts are invisible for the naked eye.

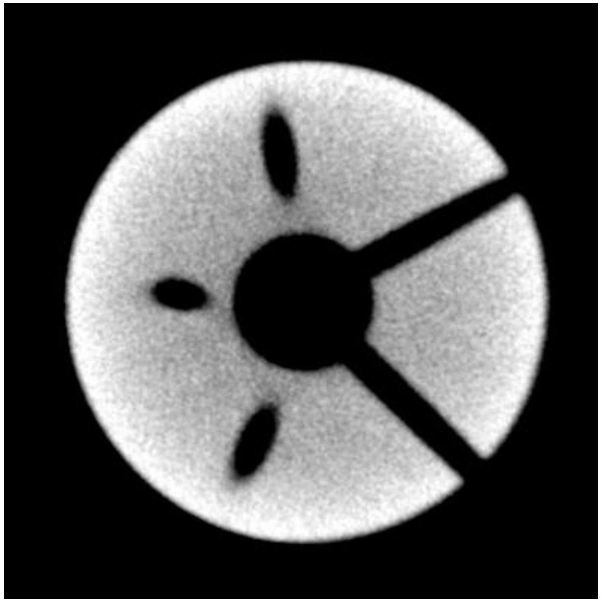


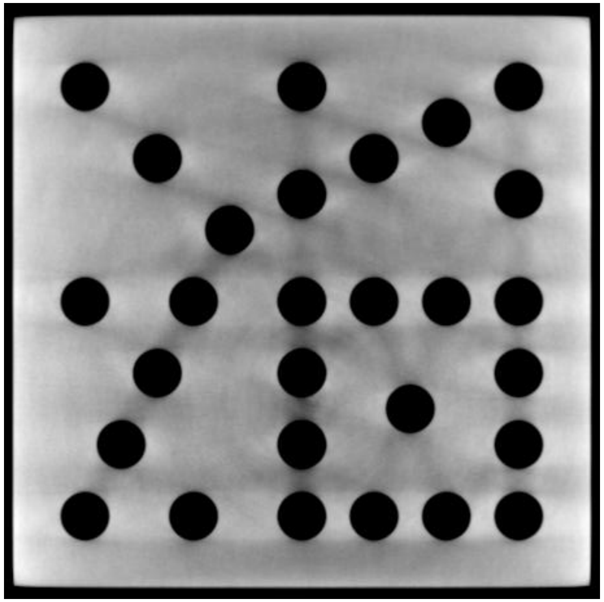


Examples of error sources

The complexity of XCT induces additional error sources, like beam hardening artifacts caused by the polychromatic X-ray spectrum.

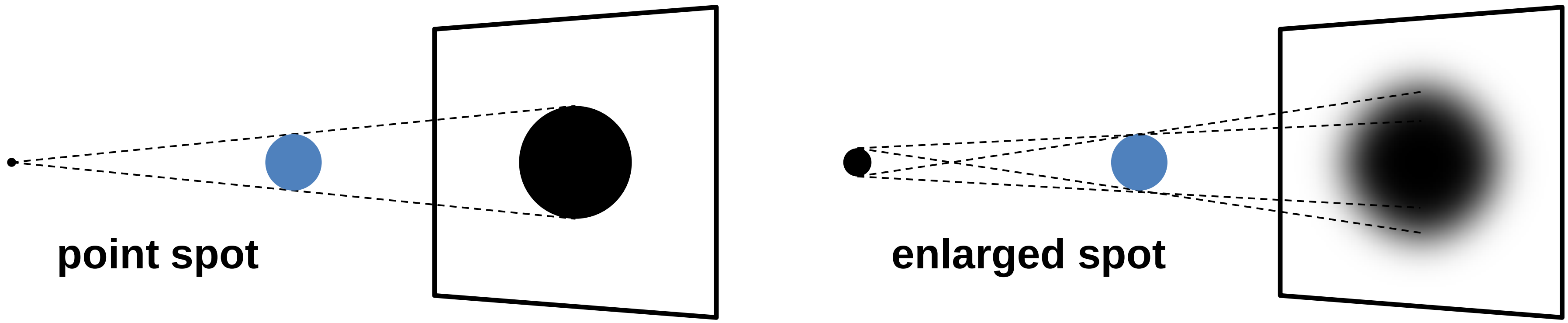
This error source is significant especially for large and high density objects.





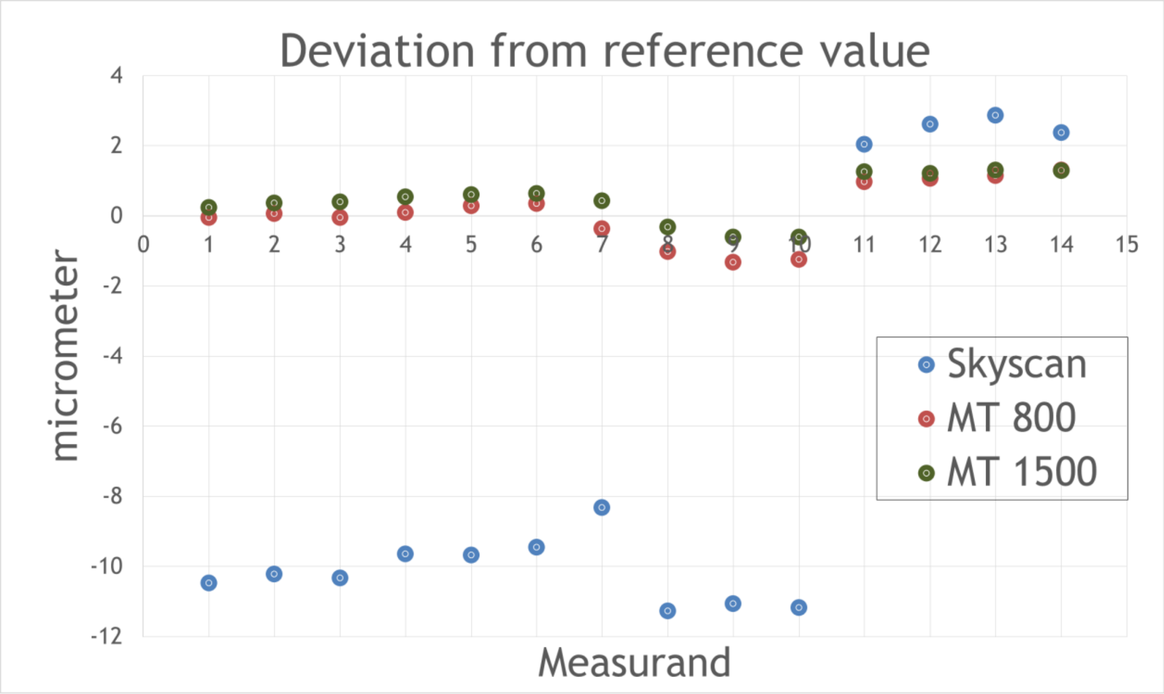
Examples of error sources

Especially for measurement of parts with small geometric features, the size of the X-ray spot plays an important role. Larger spots lead to blurred projection data, smaller geometric features are no longer resolvable.



Measurement deviations

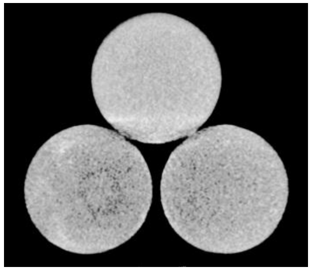
The complexity of the error sources may lead to errors in the data, that are not visible with the naked eye. Nice looking volume data does not always lead to precise measurement results!



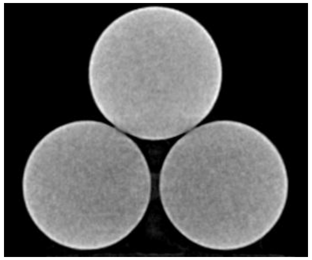
Study carried out at DTI: Andersen et al.: Comparing XCT systems. MacroScale 2014, Vienna

Micro-tetrahedron
four ruby spheres
of 0.5 mm diameter

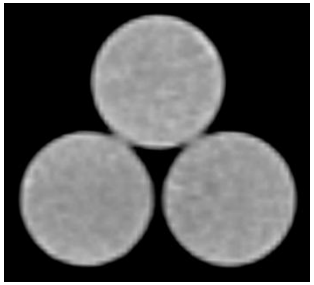
SkyScan-1172
48 kV / 9.6 W
2.66 µm voxel size



METROTOM 800
75 kV / 3.75 W
4.88 µm voxel size



METROTOM 1500
125 kV / 15.6 W
16.6 µm voxel size



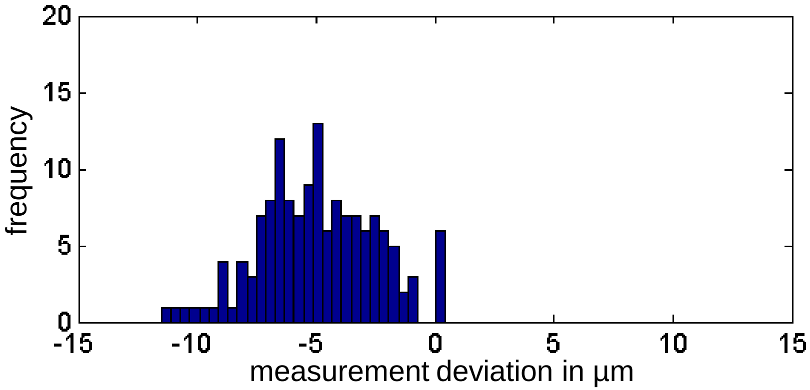
Measurement uncertainty

When it comes to dimensional measurements, knowledge of the measurement uncertainty is essential.

Measurement uncertainty determination using calibrated workpieces according to VDI/VDE 2630 part 2.1 (draft):

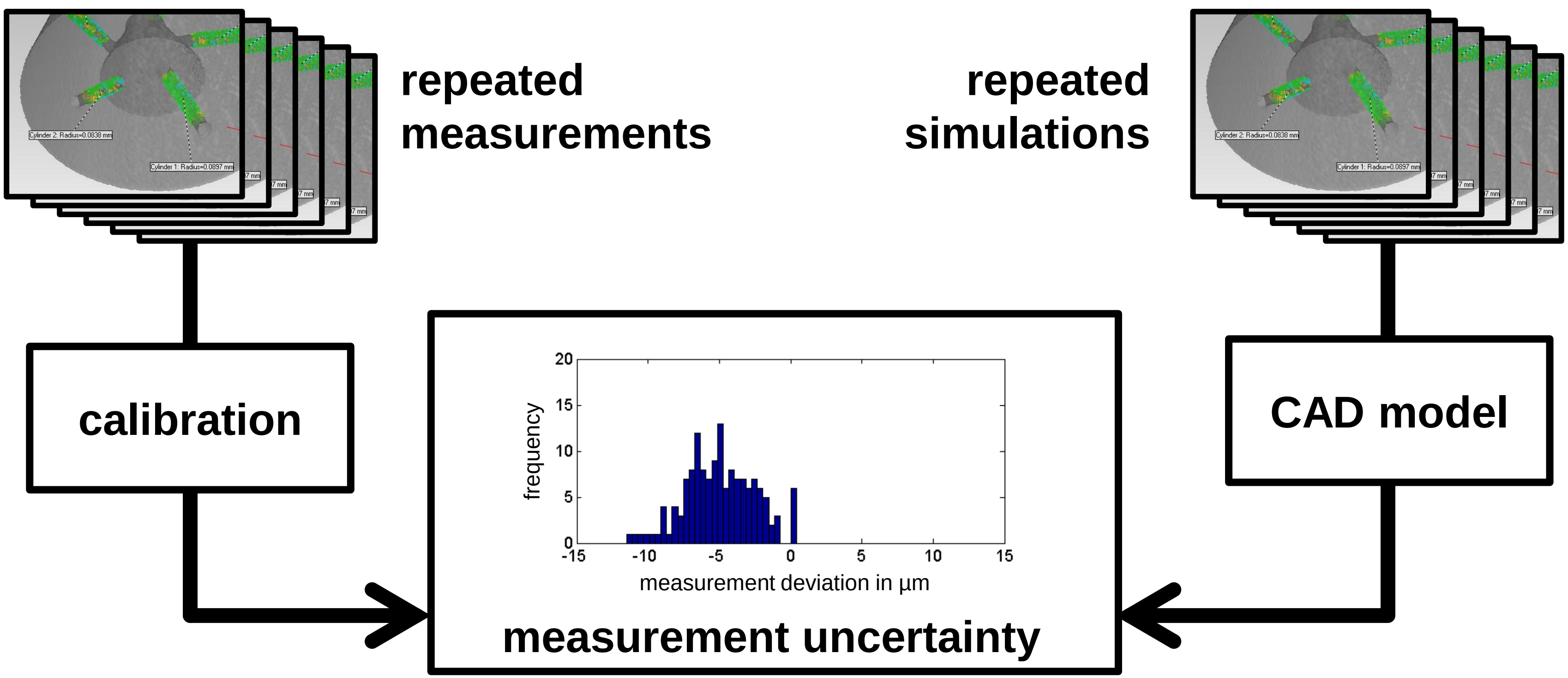
- Repeated measurement of a calibrated workpiece (at least 20x)
- Identical conditions as in the real measurement (acquisition parameters, different operators, material, penetration lengths, evaluation strategies, ...)
- Estimated measurement uncertainty is derived from a statistical evaluation of the results

Not every single influence factor is determined individually. It is assumed, that the result of the measurement contains the sum of all influences.



Numerical uncertainty determination

An alternative approach is to use a virtual metrological CT (VMCT) to estimate the measurement uncertainty.



Numerical uncertainty determination

Requirements:

- CAD model
- Simulation tool
- Deep knowledge about characteristics of all quantities significantly influencing the measurement results
    - CT system
    - Operator
    - Environment
- Computing power
- Time

Advantages:

- Task of uncertainty determination is moved away from expensive equipment
- Uncertainty determination for internal and hidden geometries without calibration
- Predetermination if possible (only the CAD model is needed)

Disadvantages:

- Large effort is needed to model the CT system
- Validity of approach still needs to be proven

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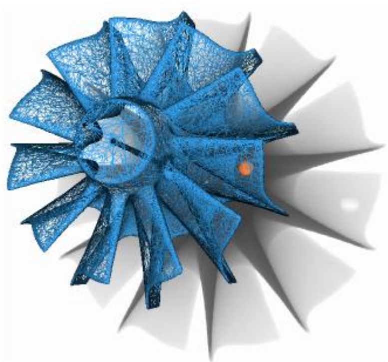
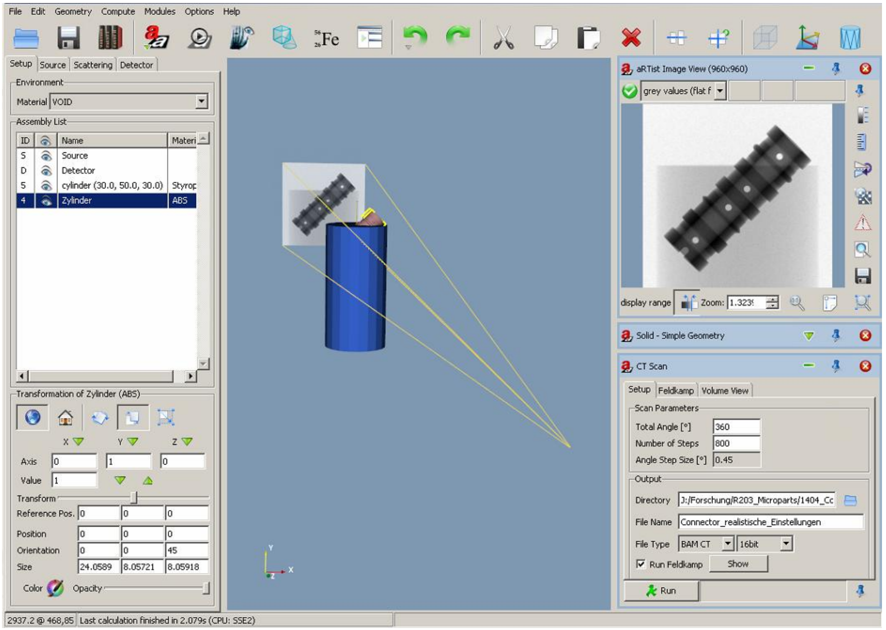
aRTist

BAM's software aRTist (analytical RT inspection simulation tool) is used to model the XCT measurement.



aRTist
analytical RT inspection simulation tool

BAM
Federal Institute for Materials Research and Testing



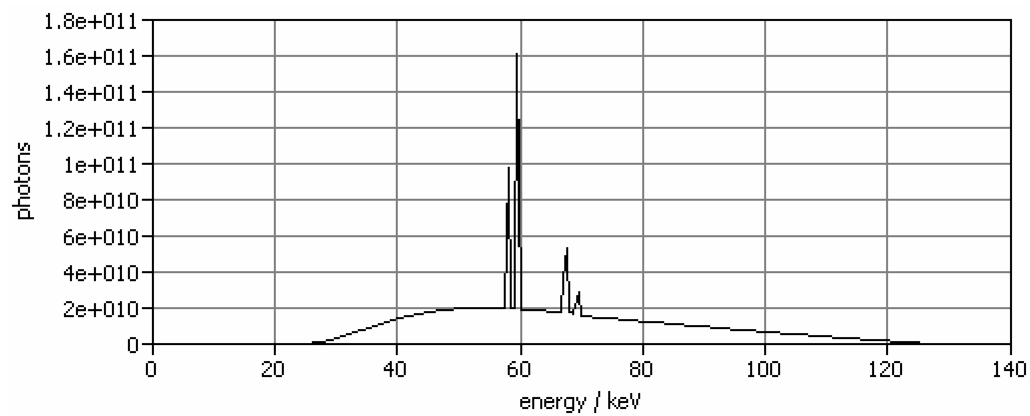
After simulating the projections and reconstructing the volume data, the same data evaluation strategies are used as for real measurements.

aRTist

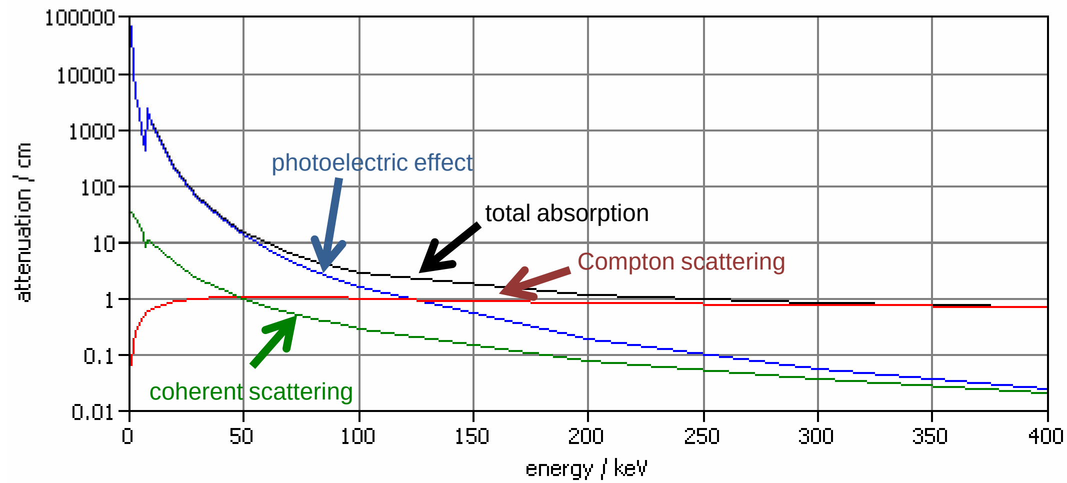
Realistic modelling of all significant error sources:

- X-ray spectrum and attenuation
- Cone-beam geometry
- Errors of kinematic system
- Spot size and drift
- Detector properties
- Geometry and temperature of workpiece
- Fixture
- …

simulated X-ray spectrum

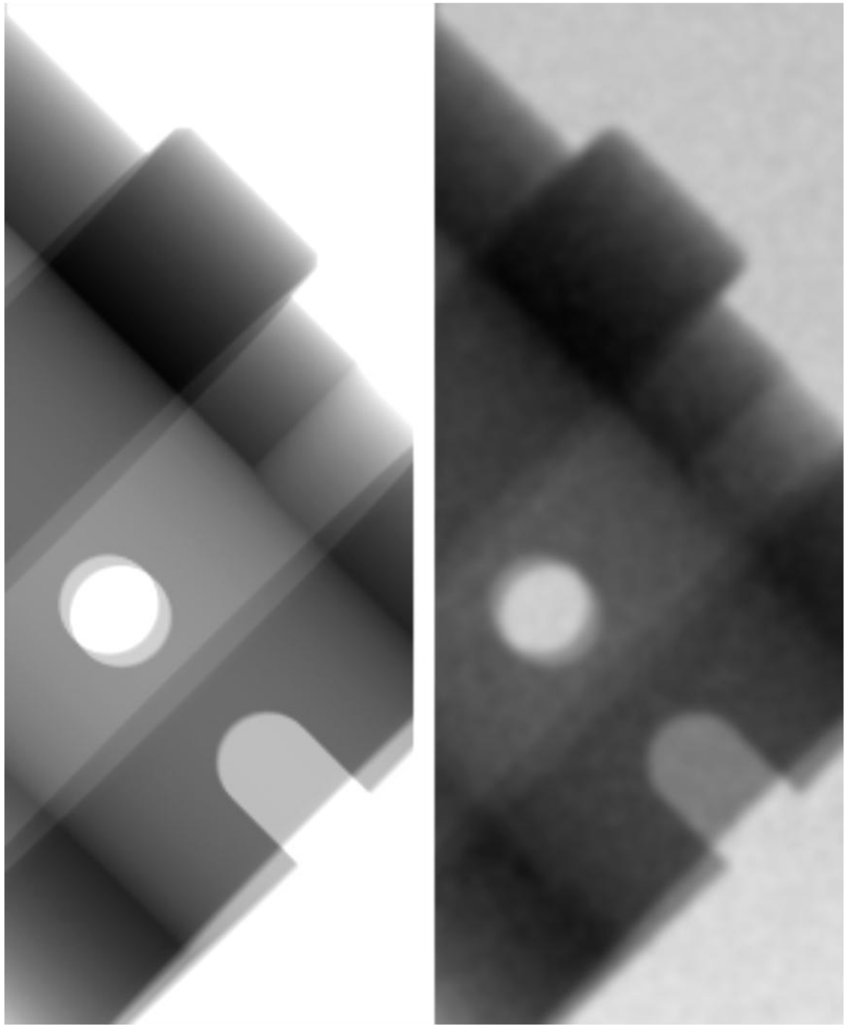


X-ray absorption of Fe



Impact of error sources

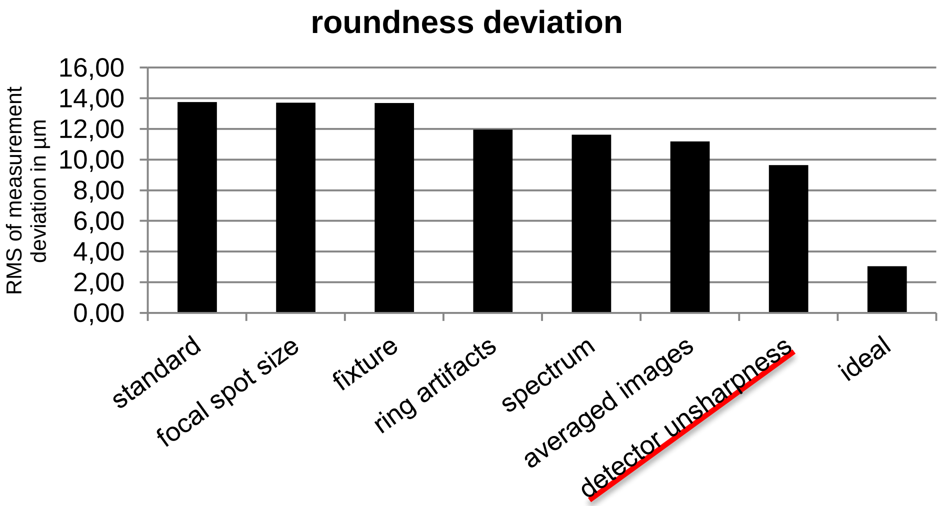
The simulation makes it possible to switch error sources on and off separately and examine their influence on different dimensional measurements



comparison of an ideal (left) and a realistic (right) projection

Impact of error sources

- **Example: roundness deviation**
- For the investigated measurement task, detector unsharpness is dominant for the examined error sources, as its absence causes the largest decrease of typical measurement deviations
- Switching of all listed error sources decreases typical measurement deviations by nearly 80%
- *Please note: the results strongly depend on the specific measurement task*



detector unsharpness	RMS of measurement deviation in µm: **unidirectional lengths**	RMS of measurement deviation in µm: **bidirectional lengths**	RMS of measurement deviation in µm: **roundness deviations**
activated	1.16	3.27	13.75
deactivated	0.37	3.11	9.65

When it comes to measurements with micrometer accuracy, there is still a lot to be done to fully understand the impact of the various error sources. However, this also means that there is still plenty of room left for improvement.

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Thank you for your attention!

We wish to thank Dr. rer. nat. Andreas Staude (BAM) for the help in setting up the simulation tool aRTist.

The work has been carried out within the EMRP project
Multi-sensor metrology for microparts in innovative industrial products

http://www.ptb.de/emrp/microparts.html

EMRP
European Metrology Research Programme
Programme of EURAMET

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

FMT LEHRSTUHL FÜR FERTIGUNGSMESSTECHNIK