Aspects of traceability of dimensional CT measurements

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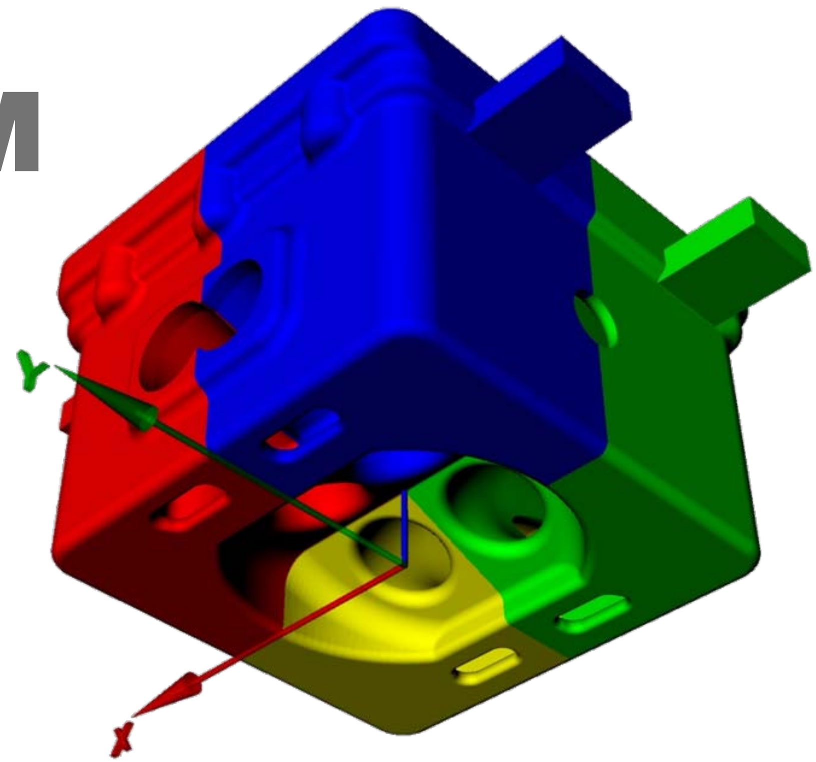
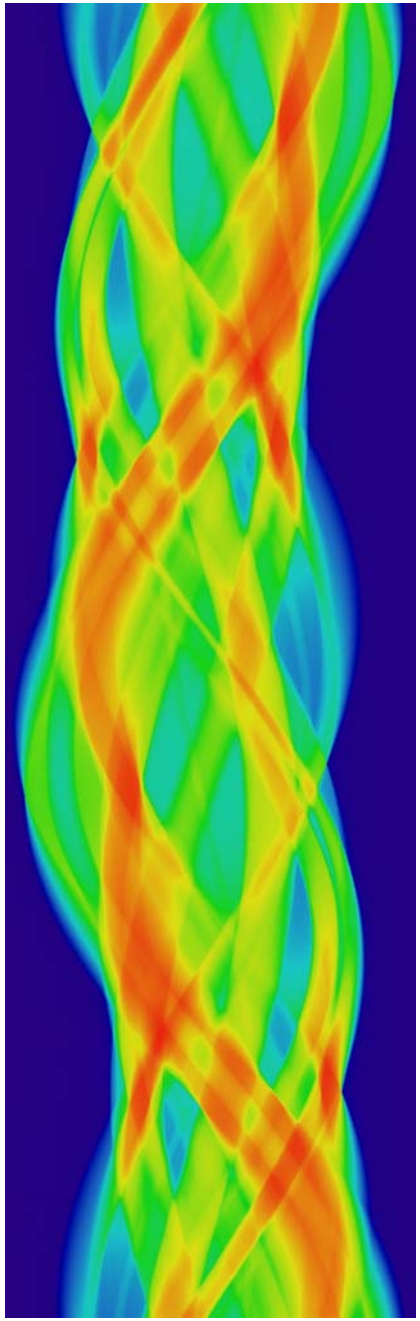


Content

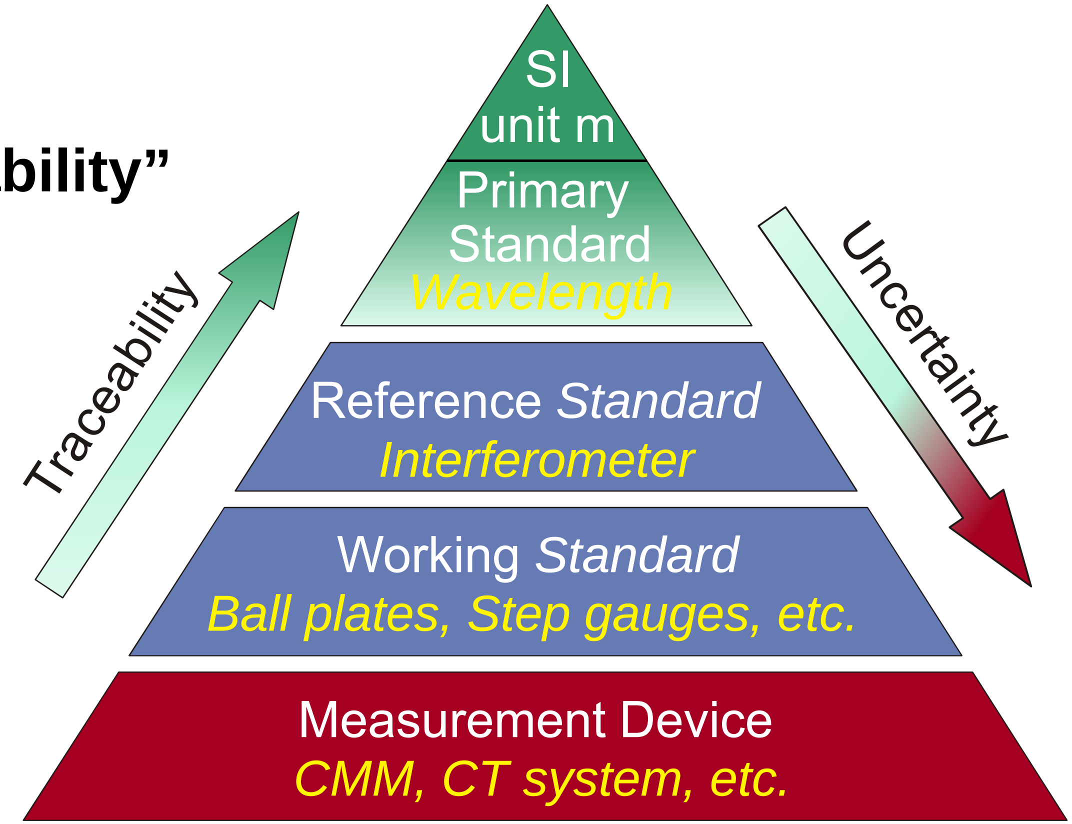


PTB – German national metrology institute

Metrological traceability often unequal to colloquial use of "traceability"

Definition:

- results traceable to SI-unit "meter"
- continuous calibration chain
- measurement uncertainty renowned

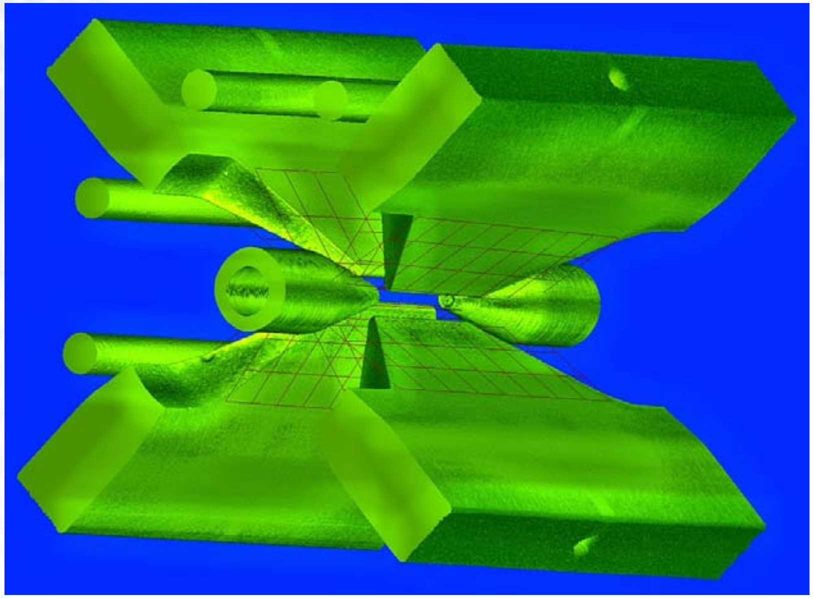


For complex measurements systems traceability is often not accomplished for all measurements; i.e. the device is not traceable.

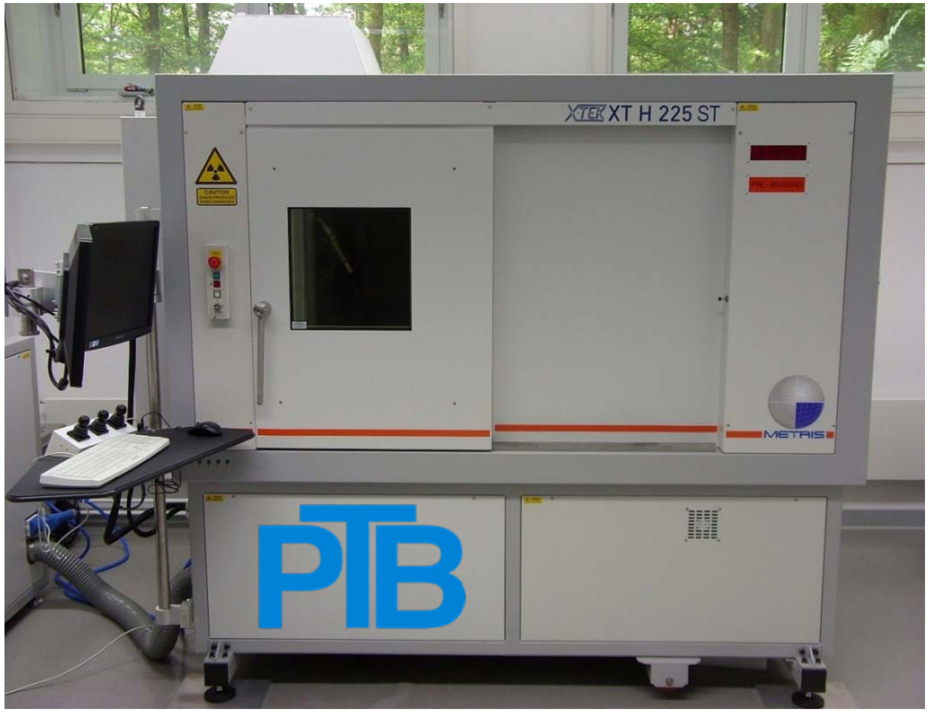
Traceability is one of the primary tasks of national metrology institutes

NIKON Metrology XT H 225 ST CT system

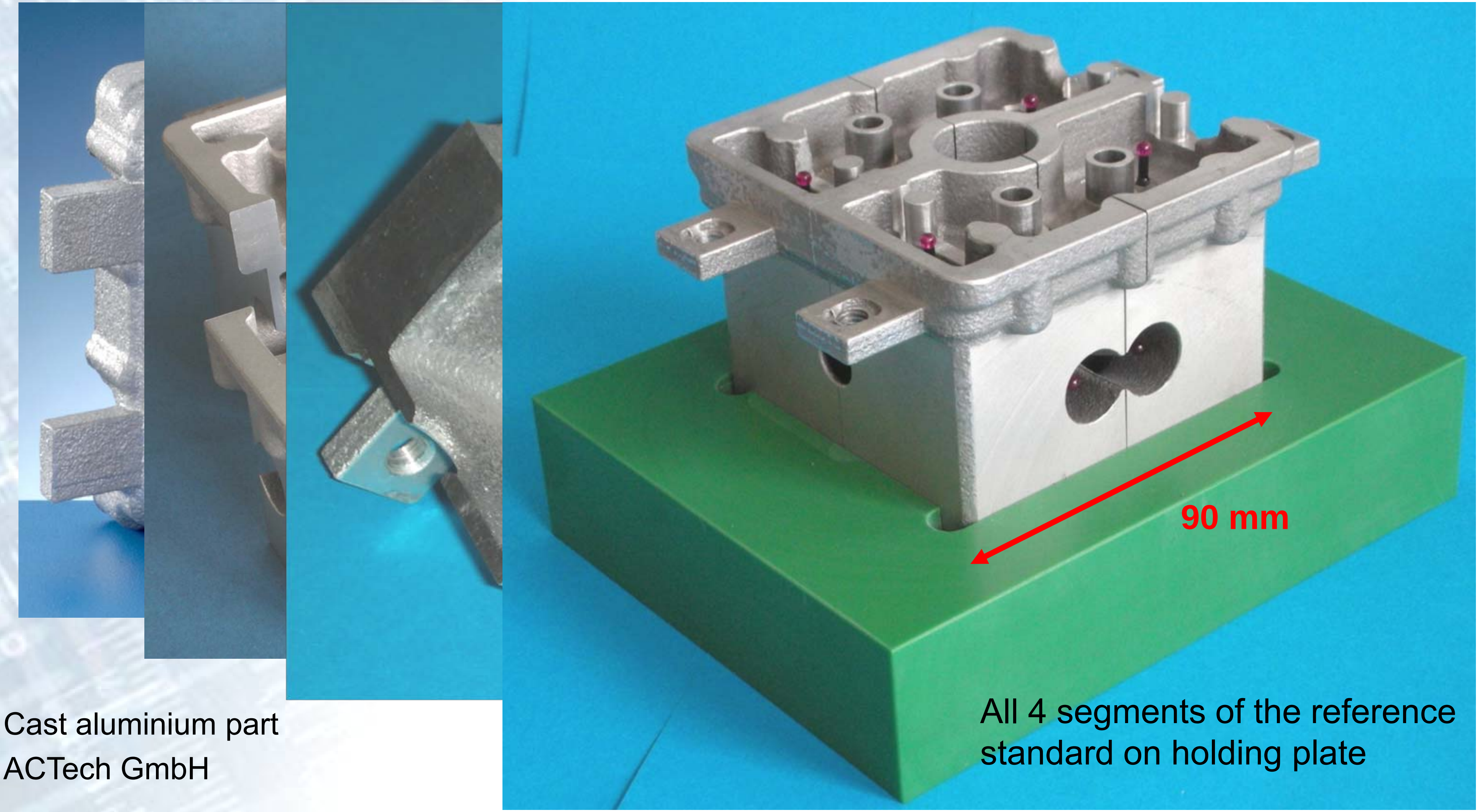
- X-ray tube with two X-ray heads:
  225 kV 225 W reflection target
  225 kV 20 W transmission target
- 2k x 2k PerkinElmer 1620 (detector size 400 mm)
- Axes with linear scales
- Fast reconstruction (5-10 min)
- 225 kV rotational target 640 W in aquisition



Ion trap
CT measurement
(J. Wübbena,
PTB, QUEST)



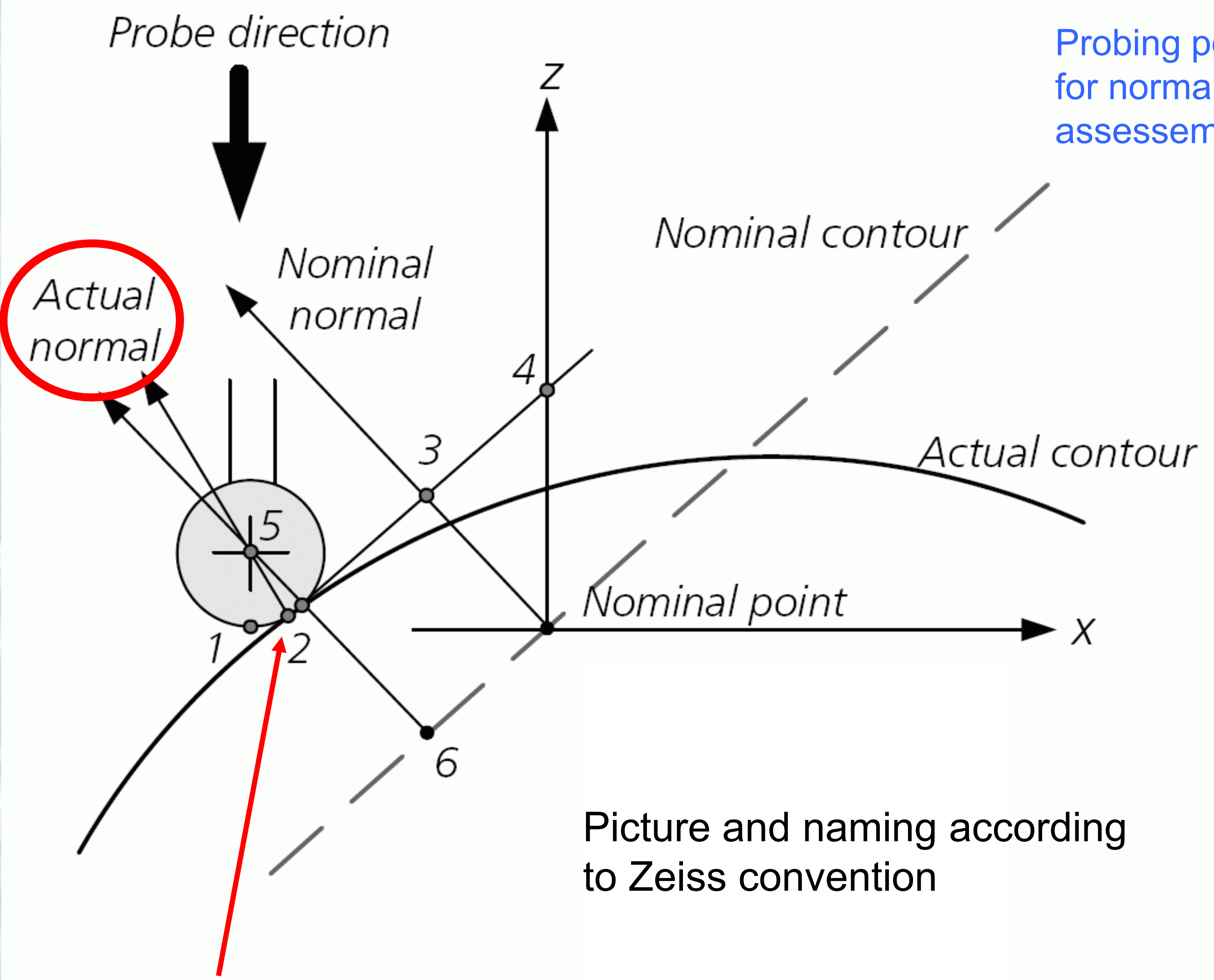
Design & manufacturing



Cast aluminium part
ACTech GmbH

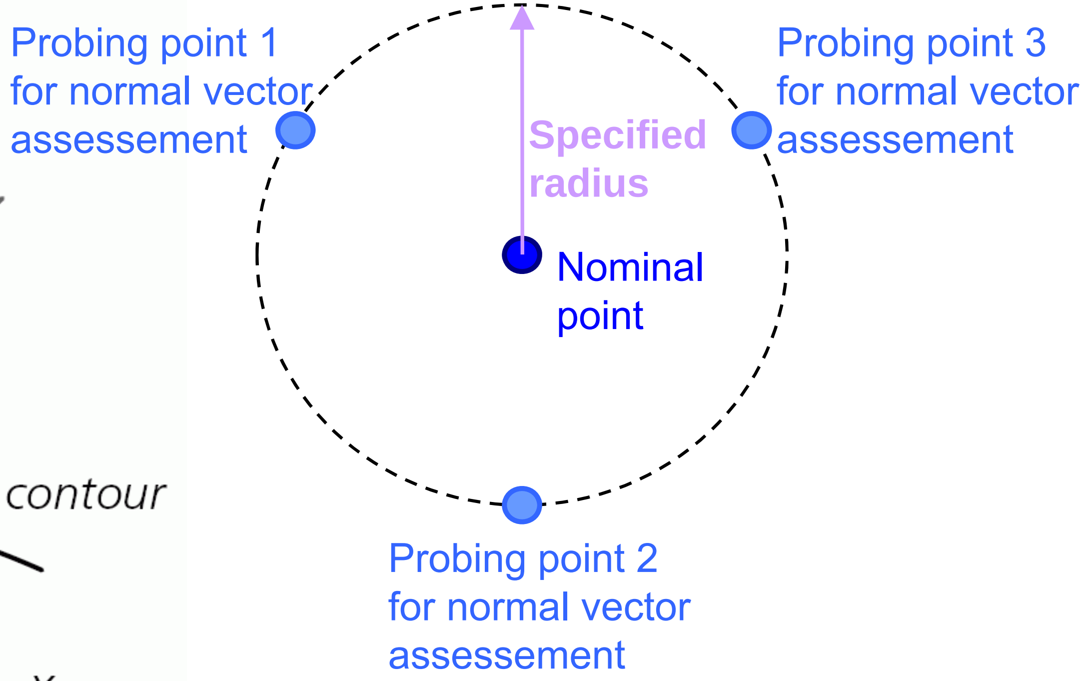
Tactile probing of freeform surface

Challenge: Probing direction, probe radius correction, point determination

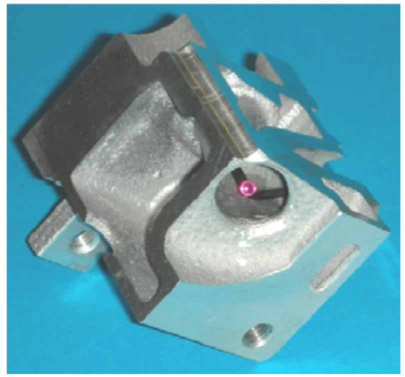


Picture and naming according to Zeiss convention

Point 2 (“Plane-point”) is the most probable contact point for the tactile probing of the surface



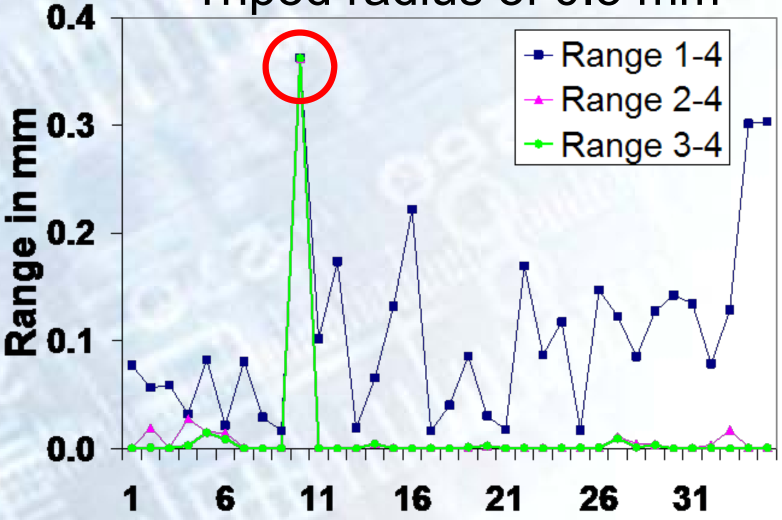
Enhanced probing scheme using Zeiss feature: “Raumpunktmessung”

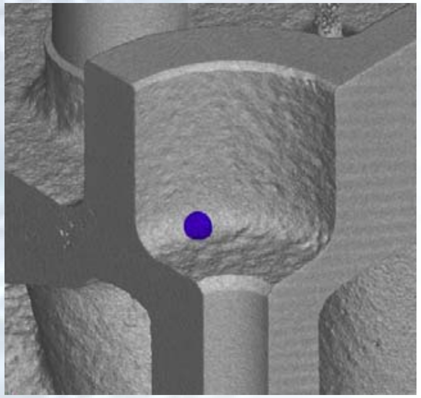


Results of iterative probing scheme

Effect in probing direction

Tripod radius of 0.5 mm





one point suspicous (unstable)

Effect perpendicular to probing direction

Iteratively measured points shift lateral on surface
→ effect of topology, sphere diameter and strategy

For tripod radius 0.5 mm
average lateral shift: 25 µm

Unstable point shows:
150 µm lateral shift

Consequences

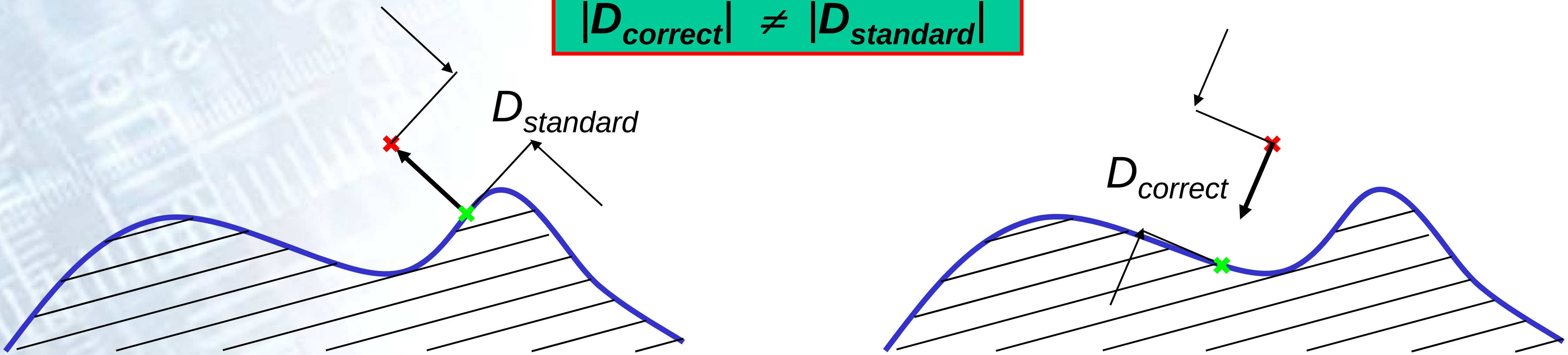
- Iterative probing success can be controlled
- Further analysis with a variable tripod necessary
- "Plane" approach may fail at certain critical points

Proper actual-nominal value comparisons

Standard (false) scheme:
Tactile CMM measurement point set as actual and surface set as reference (nominal value)

Correct scheme:
Tactile CMM measurement point and assessed surface vector set as reference (nominal value) and surface set as actual

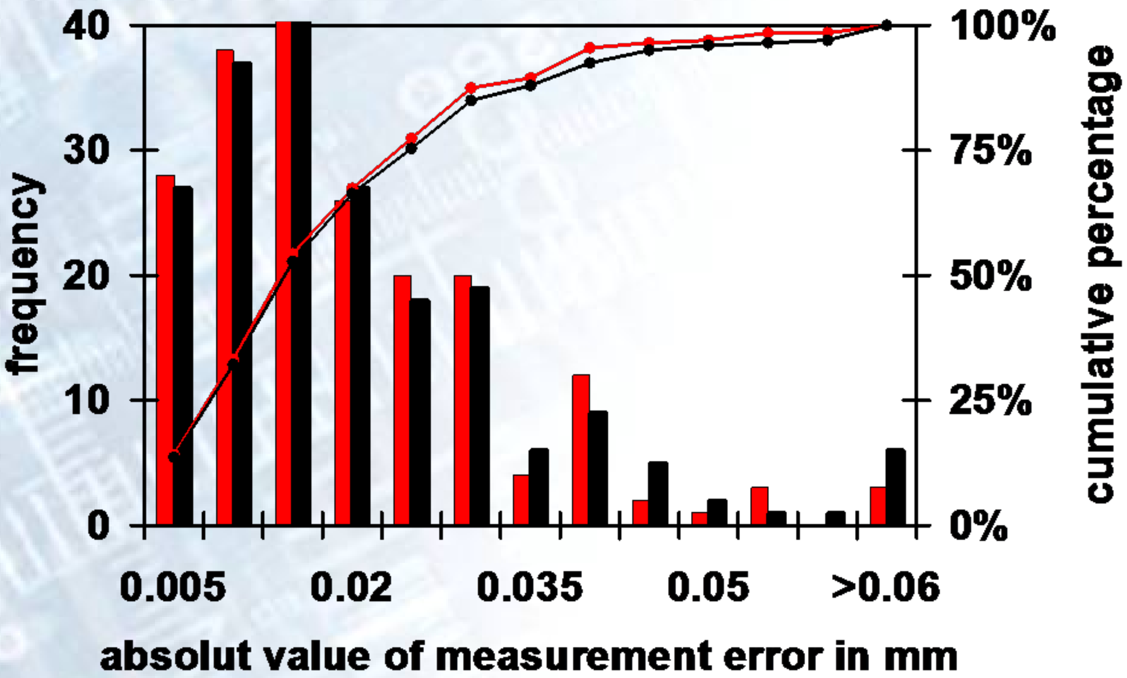
$$|D_{correct}| \neq |D_{standard}|$$

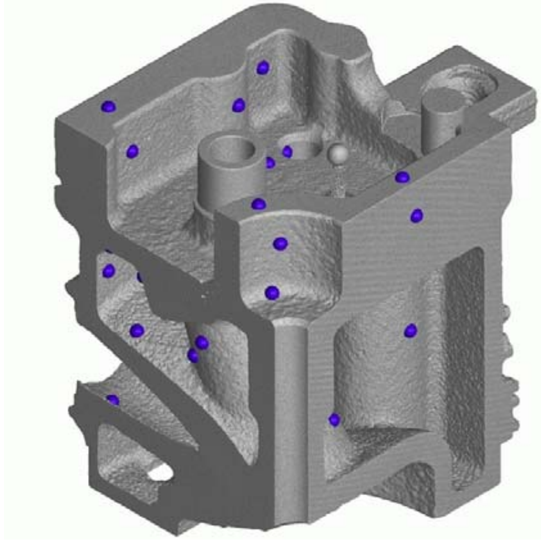


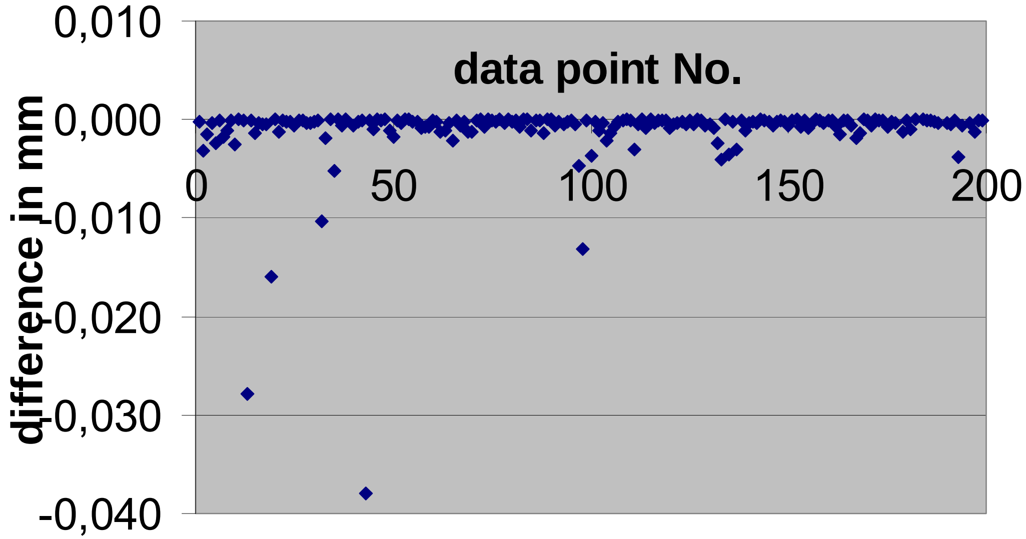
Solution for applying the correct scheme:

Use appropriate CMM measurement & actual-nominal comparison (inspection) software:
Here, ATOS 6.2 (GOM Corp., Germany) is used (data analysis Dr. Thesing, GOM)
or use successor software GOM Inspect

Measurement result:
6 CT measurements, 205 kV – 210 kV, (48 µm)³ – (105 µm)³ voxel size, analyzed at 29-35 points, iterative tactile probing







red: CT (reference) - tactile (actual)
black: tactile with normal vector (reference) - CT (actual)

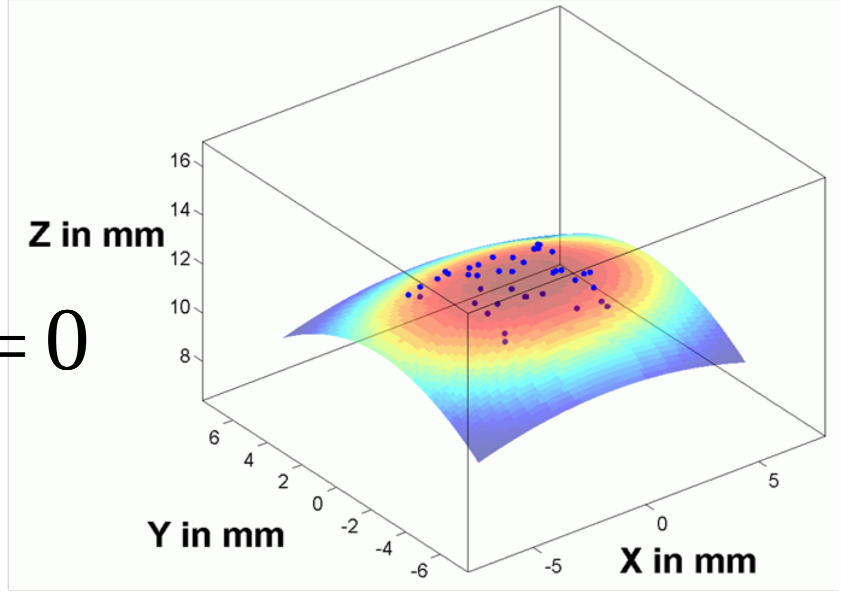
Difference between false and correct comparison scheme (difference between deviations „red minus black“)

Local modeling of surface patch by quadric

$$G(\vec{r}, \mathbf{C}, \mathbf{b}, c) = \vec{r}^T \cdot \mathbf{C} \cdot \vec{r} + 2 \cdot \mathbf{b}^T \cdot \vec{r} + c = 0$$

$$\mathbf{C} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \quad \text{with} \quad a_{mn} = a_{nm}$$

$$\mathbf{b} = \begin{bmatrix} a_{14} \\ a_{24} \\ a_{34} \end{bmatrix}, \quad c = a_{44} \quad \text{and} \quad \vec{r} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$



Observations and fitted quadric:

$\vec{r}_i$ form the observations $\mathbf{L}$

for data points i=1, …, n

$\mathbf{C}$, $\mathbf{b}$ and c form the unknown parameters $\mathbf{X}$ of the model

PTB BAM

Mathematical formulation – fitting of quadric to surface point data

$$G_i(\vec{r}_i, \mathbf{C}, \mathbf{b}, c) = 0$$ for $i = 1, \cdots, n$

$$F(\hat{\mathbf{L}}, \hat{\mathbf{X}}) = \mathbf{B} \cdot \mathbf{v} + \mathbf{A} \cdot \hat{\mathbf{x}} + F(\mathbf{L}, \mathbf{X}^0) = 0$$ Linearization (Gauß-Helmert)

$\hat{\mathbf{x}} = \hat{\mathbf{X}} - \mathbf{X}^0$ the reduced parameter vector

$\mathbf{v} = (\hat{\mathbf{L}} - \mathbf{L})$ the vector of residuals

$F(\mathbf{L}, \mathbf{X}^0)$ the inconsistency values

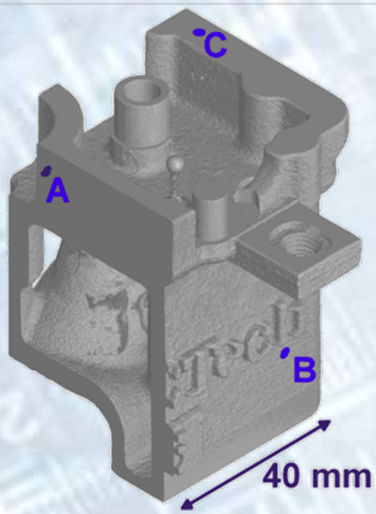
$$\sum_i \mathbf{v}_i^2 \rightarrow \min$$

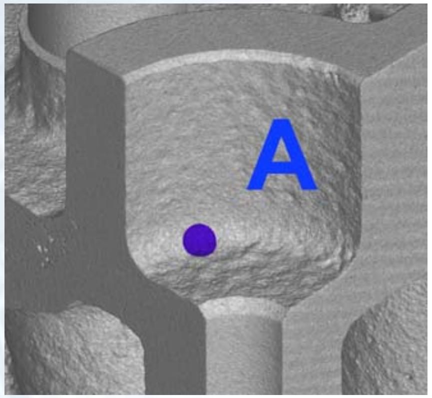
$$\Omega = \mathbf{v}^T \mathbf{v} - 2 \cdot \mathbf{k}^T \cdot F(\hat{\mathbf{L}}, \hat{\mathbf{X}})$$ with korrelates $\mathbf{k}$

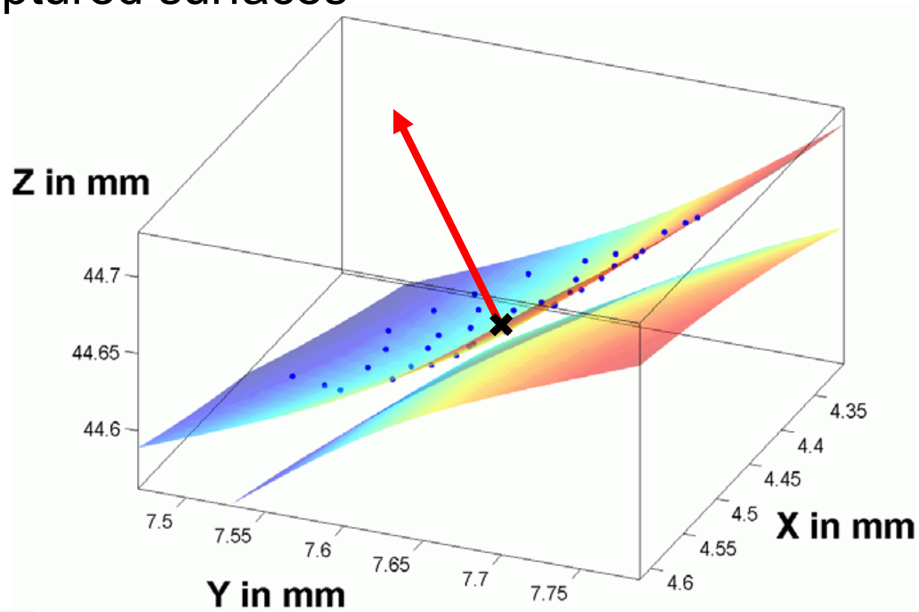
Implementation in MATLAB R2009a (using standard modules only)

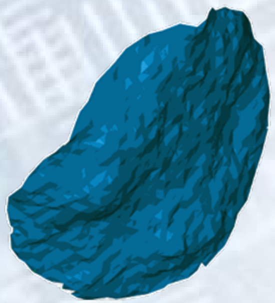
Mathematical formulation – results from real point data (CT data)

Data points from real CT data of cast part with sculptured surfaces

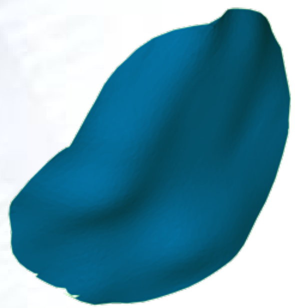




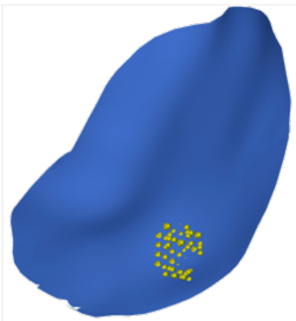




Raw CT data



filtered CT data
(Geomagic Studio)



filtered CT data
with selected points

Time of fit (38 points): 0.2 s

Final result:
coordinates *x*, *y*, *z* and
surface normal *nx*, *ny*, *nz*
of assessed surface point

Update of ISO 15530-3 treatment of systematic errors (ISO TC 213 WG10)

Procedure of ISO 15530-3:2004 for uncorrected systematic errors was not consistent with GUM

$$Y = y - b \pm U$$

According to GUM systematic error *b* has to be corrected and to be stated in the result *Y*

$$U = k\sqrt{u_{cal}^2 + u_p^2 + u_w^2 + u_b^2}$$

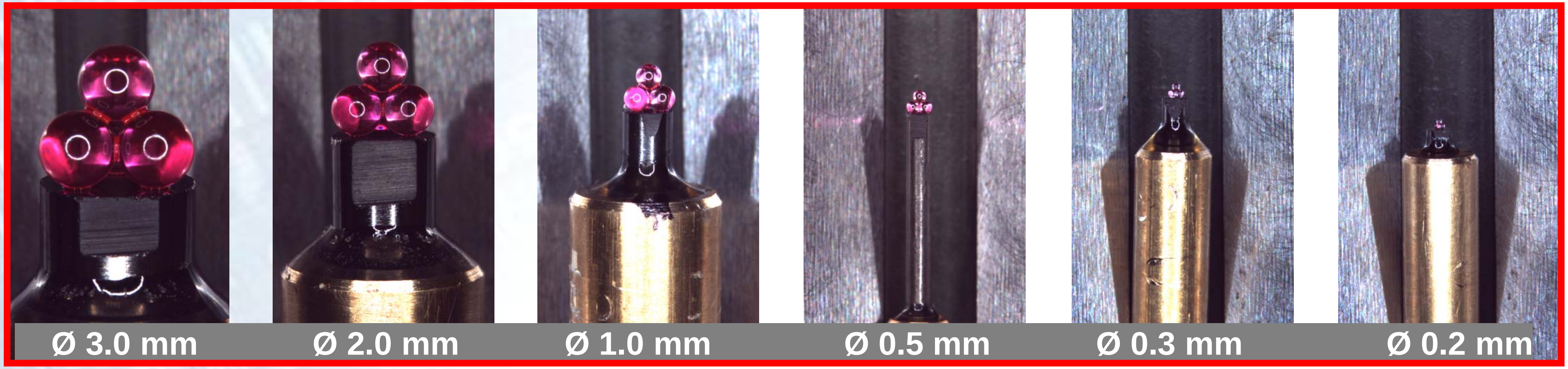
rewritten formula conformant to GUM

Additional treatment of uncorrected systematic errors *b* in upcoming VDI/VDE 2630-2.1 draft

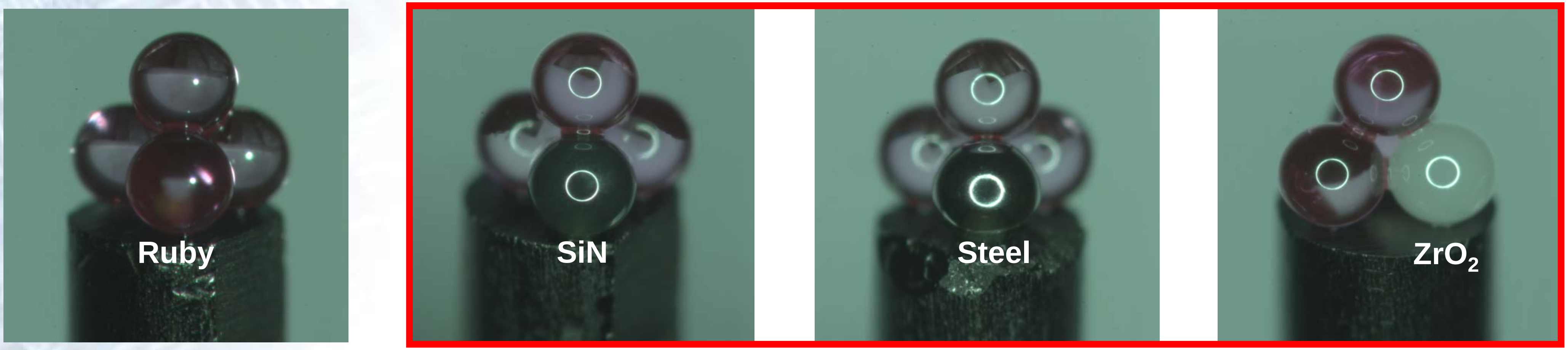
$$U = k\sqrt{u_{cal}^2 + u_p^2 + u_w^2 + b^2}$$

rewritten formula conformant to GUM

Task specific microtetradheron standards (made by PTB)



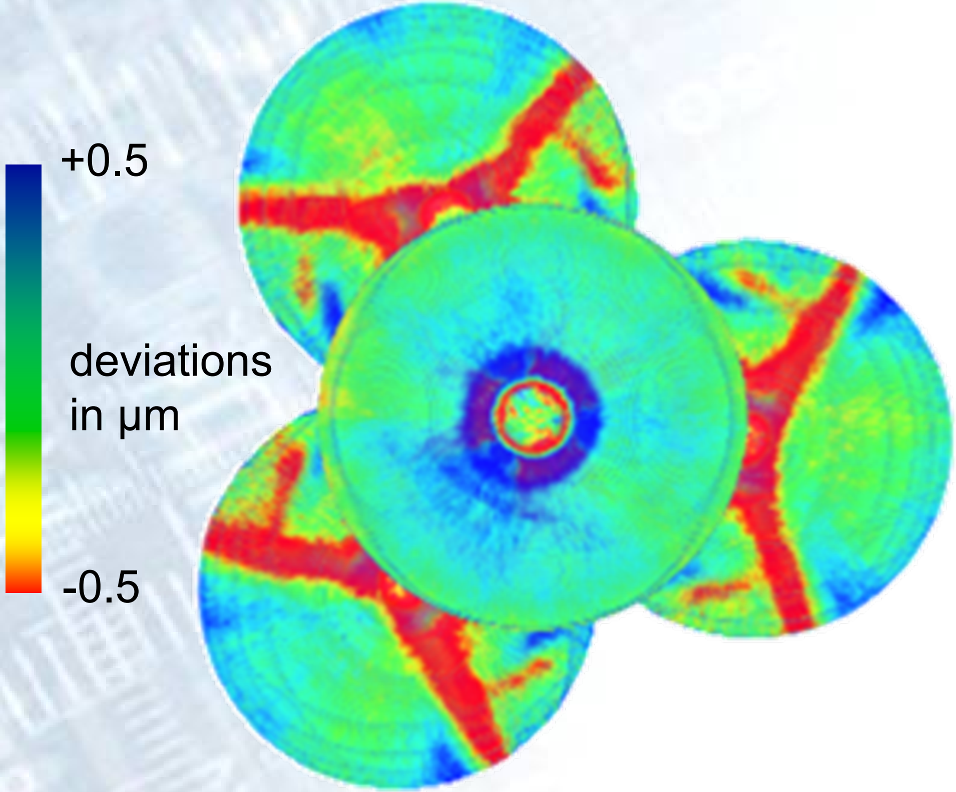
Microtetrahedrons with stepped size with 4 ruby sphere, respectively



Microtetrahedrons with 3 ruby spheres and one sphere of different material (all Ø 0.5 mm)

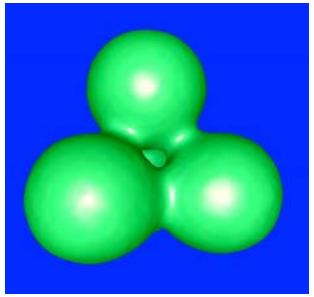
Manufacturing of tetrahedrons
Dr. R. Meeß, J. Brzoska, A. Jung (PTB)

Applications of microtetrahedrons (here 4 ruby spheres Ø 0.5 mm)
Analysis of systematic errors and effects

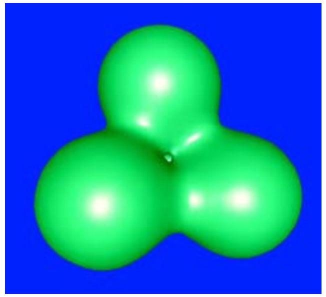


µCT 40 kV
BAM (225 kV CT system)

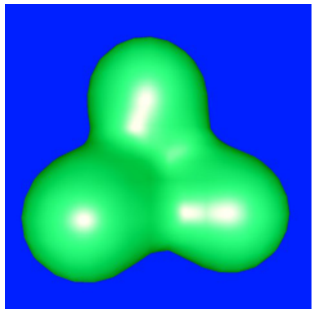
ISO study structural resolution for TC 213 WG 10 (38 kV, industrial CT system)



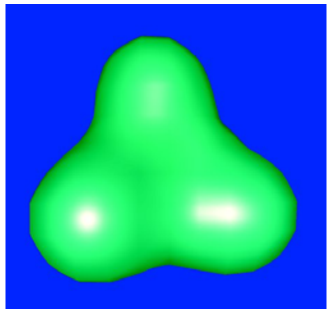
Magnification: 6.0



3.0



Magnification: 2.0

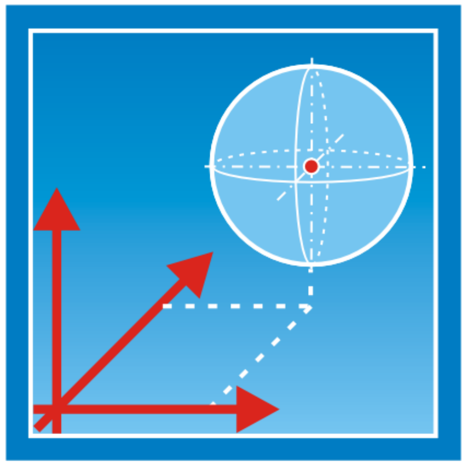


1.34

<u>Criteria for structural resolution limits are to be defined</u>

Conclusions

- **Traceability** is the core objective for any measurement technique
- **Certain aspects** and challenges have been addressed **for CT systems**:
  - use of dismountable reference standard
  - correct calibration & analysis of freeforms and assessed datasets
  - enhanced probing scheme for freeform surfaces
  - treatment of systematic errors according to ISO 15530 & VDI 2630-2.1
- **Micro CT** requires dedicated reference standards, e.g. tetrahedrons.
  Applications of standards up to now can be the analysis of systematic effect, system approval and structural resolution analysis



Thank you for your attention!

The authors thank for their contribution

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Activities supported by the German Research Foundation (DFG) project No. NE 757/2-2 and by the German Federal Ministry of Economics & Technology project No. AZ:II D5 –07/06