Application of CT Scanning in Industry
Danish Technological Institute

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Measurement of micro moulded parts by Computed Tomography

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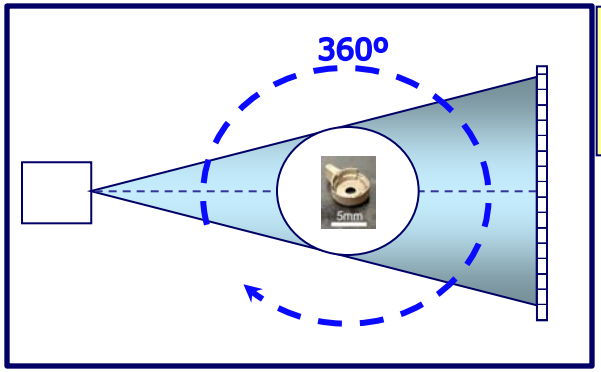
Objectives

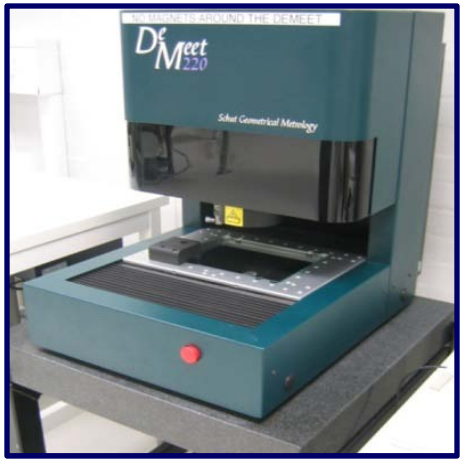
- Dimensional verification of 2 micro-injection moulded components (actual industrial productions) using CT metrology.
- Comparison Computer Tomography vs. CMM vs. OCMM.

CT



U.Z
U.P

OCMM



DTU

DTU

CMM

Outline

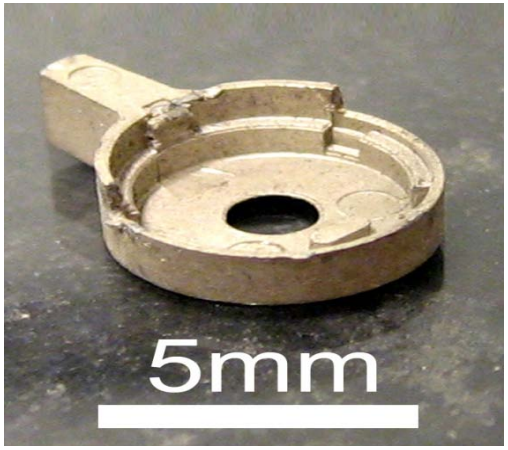
1. Introduction

- Accuracy and time demands tighter and tighter → **smaller mechanical parts** are characterized by smaller tolerances to be verified.
- Dimensional metrology demands → optimization of traditional metrology equipments + **new technologies** based on new measuring concepts.
- **Computed Tomography** (CT) metrology techniques are more and more applied for micro-parts geometrical verification:
  - Advantages: non-contact, dense scanning and the capability of measuring both internal and external geometries simultaneously.
  - On the other hand: their uncertainty is still high compared to CMMs or even OCMMs.

2. Materials and methods: work parts

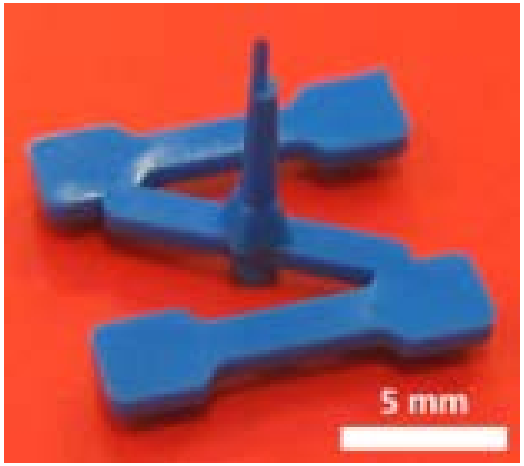
- 2 polymer micro products fabricated using micro injection moulding technology.

- Previous estimation of the process capability and measurement uncertainty → G. Tosello, H.N. Hansen, S. Gasparin "Applications of dimensional micro metrology to the product and process quality control in manufacturing of precision polymer micro components" CIRP Annals - Manufacturing Technology 58 (2009) 467–472



3 Toggles for a hearing aid application made of liquid crystal polymer (LCP).
Part weight: 35 mg.

DTU

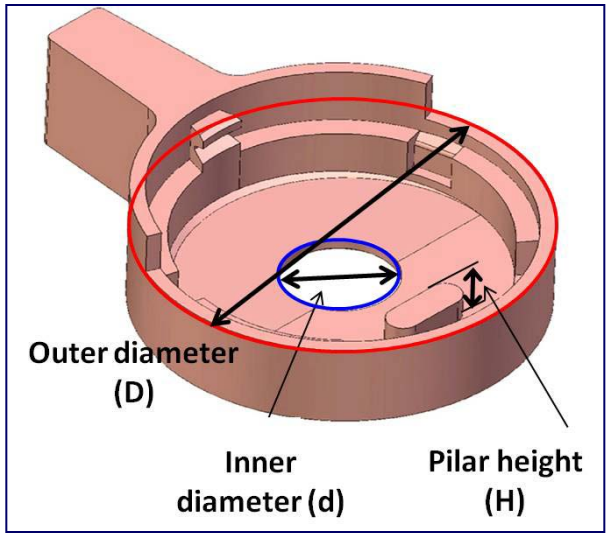


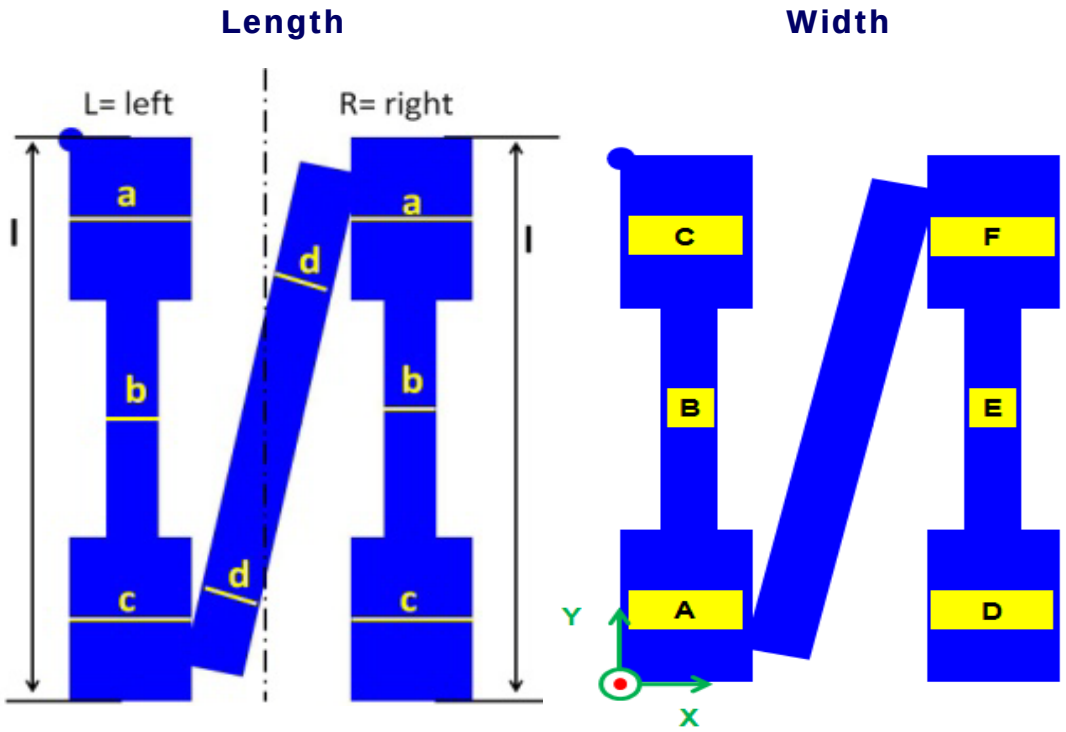
5 Dog Bones used for micro mechanical material tensile testing, made of acetal polyoxymethylene (POM).
Part weight: 35 mg.

* ISO 527-2:1993: Test conditions for moulding and extrusion plastics

Dimensions

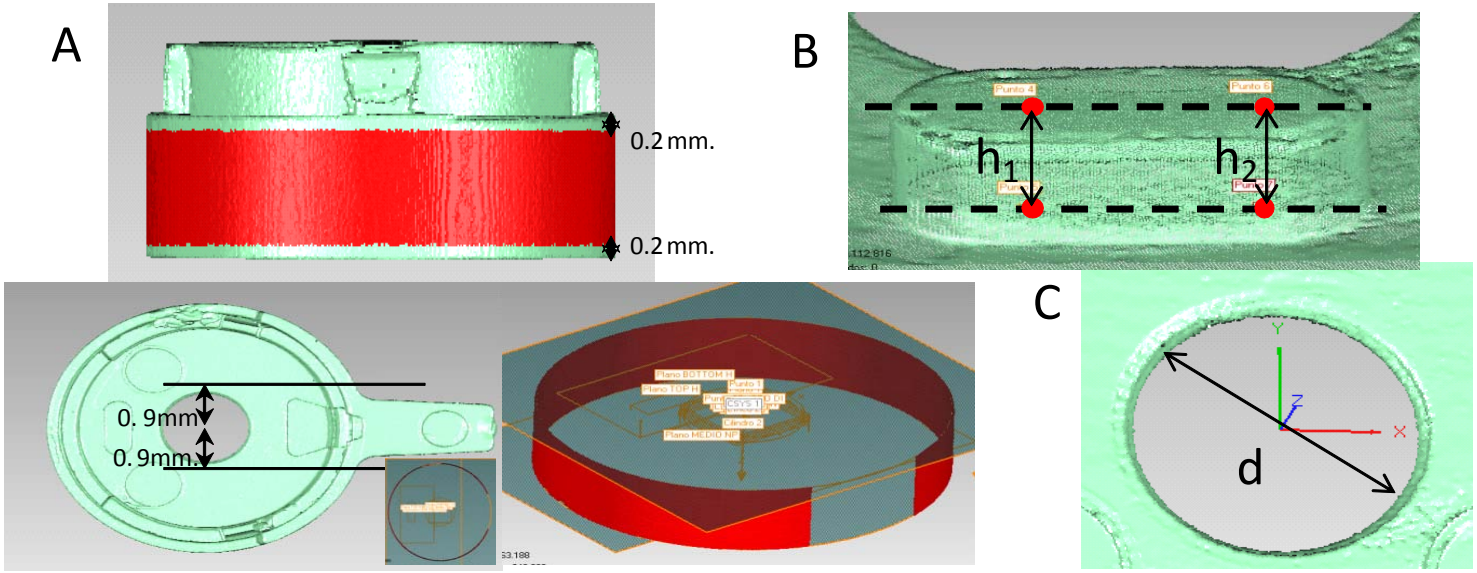
- Both internal and external geometries (part thickness, internal and external diameter and part length).
- 3 different measuring techniques: CT, CMM, and OCMM



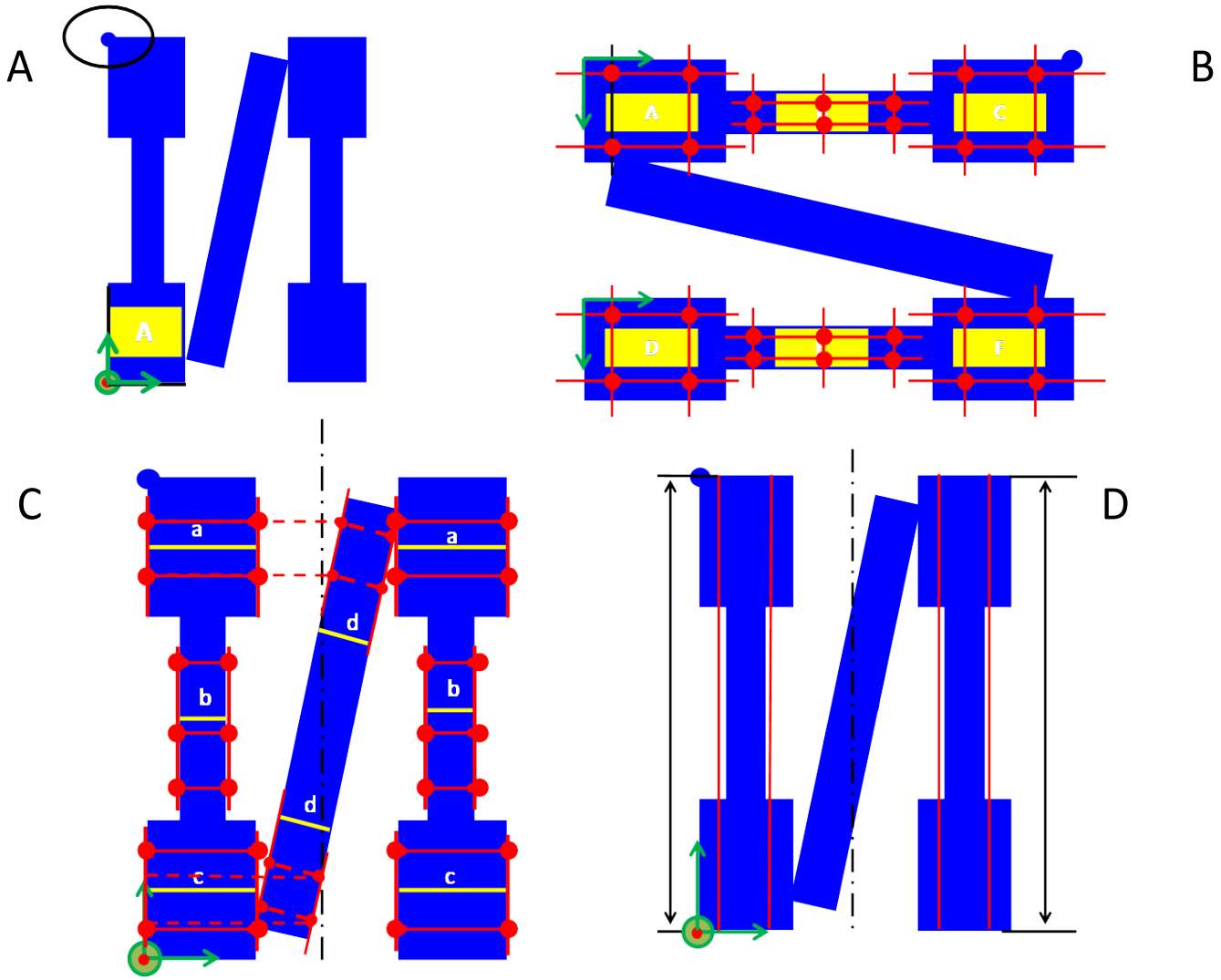


Measuring procedure

- The significant form errors of the samples → different measurand definitions → different measuring systems → different measuring results.
- This influence has been minimized by using a common measuring procedure.



Measuring procedure



Measuring machines: CT1

U.Z

- Micro-CT Scanner: General Electric
- Model: eXplore Locus SP
- X Ray source power: 50-80 KV!!
- Detector 2D: 2300x3500
- Maximum resolution: 8 µm
- Maximum dimensions :

  Diameter: 44 mm

  Height: 56 mm
- Micro-View + Mimics + Geomagic
- Micro-View + Mimics / VGS + Calypso

Measuring machines: CT2

- Micro-CT Scanner: Tomolab (developed by the ELETTRA Laboratory in Trieste)
- cone-beam microCT
- X Ray source power: 40-130 KV
- Spot size: 5 µm
- Maximum dimensions:

  Diameter: 45 mm

U.P

Measuring machines: OCMM and CMM

DTU

- OCMM: DeMeet 220 (2½ D)
- Measuring volume 220 mm x 150 mm x 100 mm
- MPE_{X-Y} = 4 + L/150 µm, L in mm
- MPE_{Z} = 3.5 µm
- Fast measurements and in-line quality
- Validation instrument

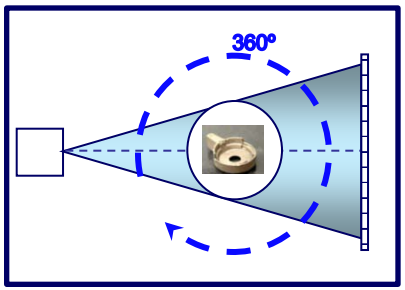
- Tactile CMM: measuring volume 850 mm x 1150 mm x 600 mm
- MPE = 0.4 + L/900 µm, L in mm
- Toggle parts measured → OCMM compensation
- G. Tosello, H.N. Hansen, S. Gasparin "Applications of dimensional micro metrology to the product and process quality control in manufacturing of precision polymer micro components" CIRP Annals - Manufacturing Technology 58 (2009) 467–472

Outline

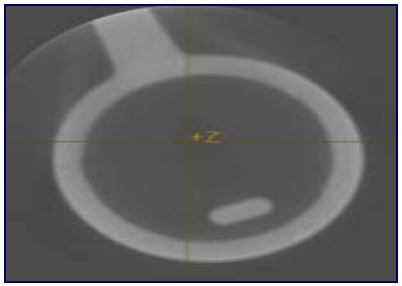
1. Introduction
2. Materials and methods
3. **Metrology using CT. Some considerations**
4. Results
5. Conclusions
6. Other interesting parts

3. CT Metrology: Process

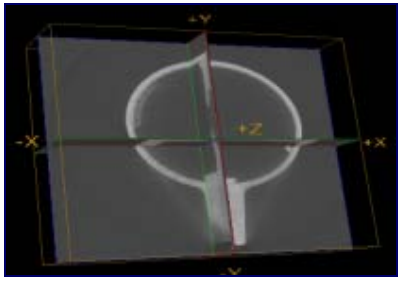
Work Piece



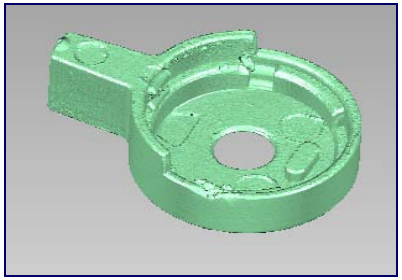
Scanning



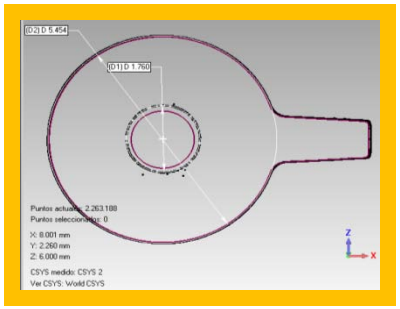
Slices



Reconstruction



Surface Extraction



Evaluation

Correction factors

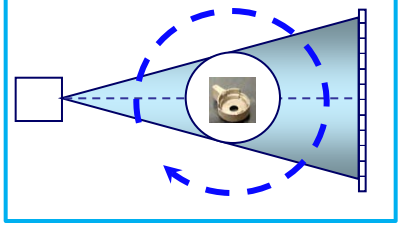
Error sources

Work Piece

Environment

Detector

Tomography



X-Ray

SOD

User

Rotary Table

Format file

Image quality

Reconstruction

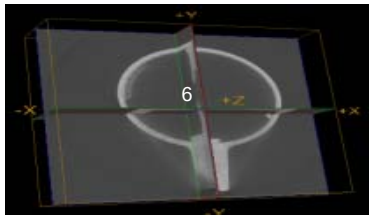


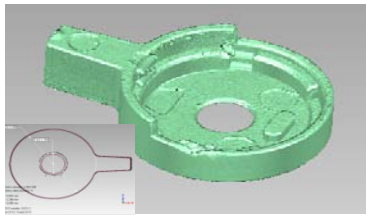
Image Correction

Reconstruction Software

Software

Threshold determination

Post-Process



Strategy

Correction Factors

Tomography: error sources

SOD

$$\text{Voxel size} = \text{pixel size} \times \left(\frac{\text{SOD}_i + \delta}{\text{SDD}_i + \delta} \right)$$

Detector position, rotary stage position and pixel size can be determined “permanently”

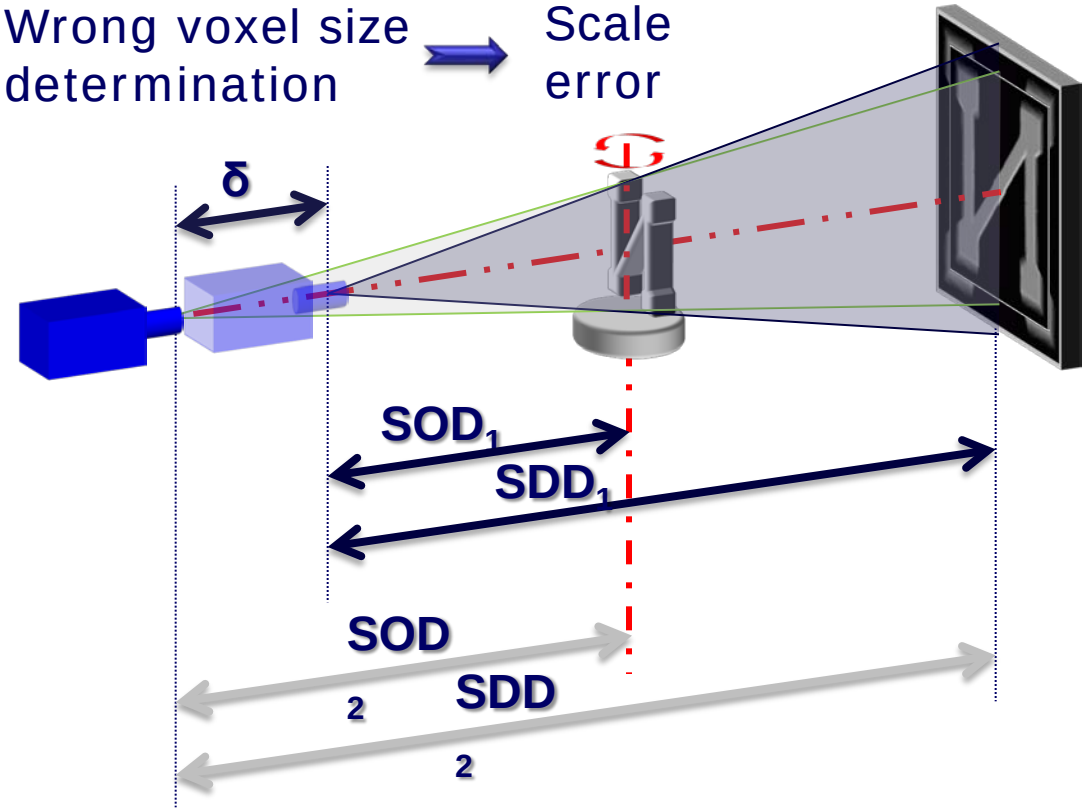
The position of the focus of X-ray source can change uncontrollably

$$\delta = f(V, I, \Delta T, t...)$$

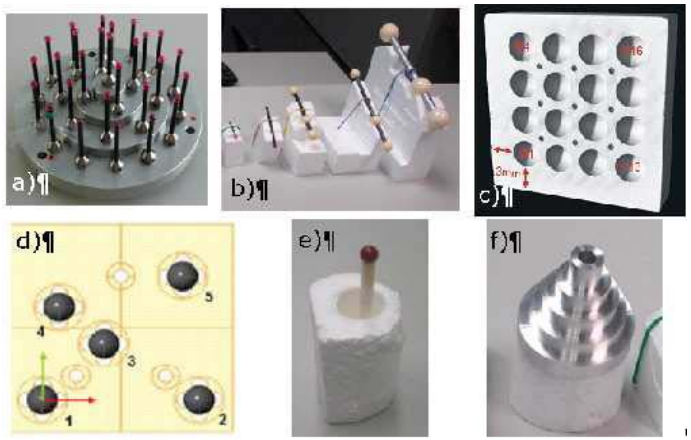
Wrong voxel size determination → Scale error

Conclusions:

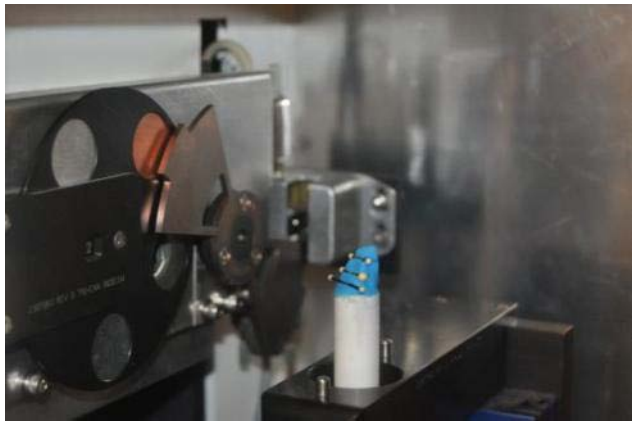
- Calibrate for each part
- The angle of incidence between the x-ray source and the detector affects accuracy, more than the magnification. (Acc. to Angela Cantatore)



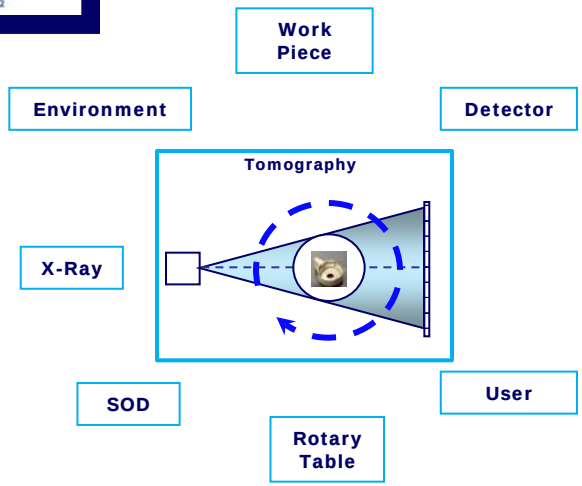
MPE and scale factor



- Previous studies on determination of MPE_E, $MPE_{(PF+PS)}$, MPE_{GR}
- Voxel size determination → Scale factor (specially in Micro-CT) → Ball bars
- Ball bar together with the part is one possible option



Tomography: error sources



DETECTOR

The detector influences the contrast, the pixel variance, noise, etc.

ROTARY TABLE

The rotary table has much higher impact in: sharpness, resolution and accuracy.

WORK PIECE

Material stability

Use workpieces of high aspect ratios and differently absorbing materials in measurements

Quantification of the influences the operator typically decides during the preparation of a measurement:

- Orientation of the workpiece
- Magnification (different voxel size)
- Number of projections or angle increment between the radiographs.

Reconstruction: error sources

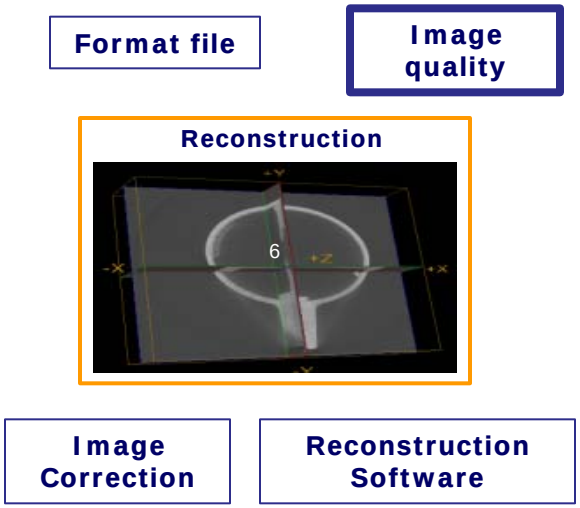


IMAGE QUALITY

Features to evaluate in the image quality:

- Distortions.
- Artifacts.
- Uniformity of response throughout the area of the detector.
- Bad pixels.

CT Image quality

Format file

Image quality

Reconstruction

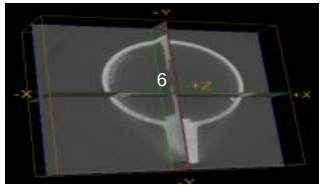
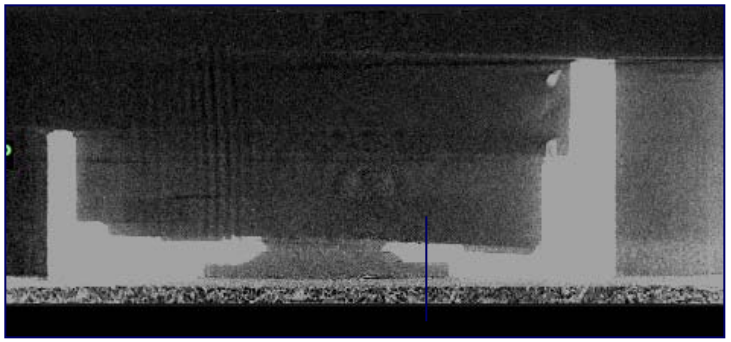


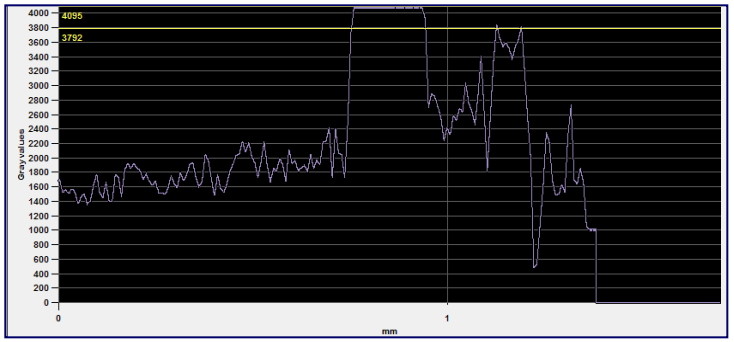
Image Correction

Reconstruction Software

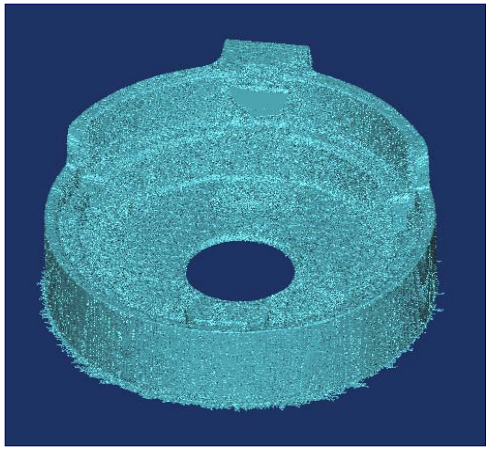
Greyscale value non-homogeneus



Profile

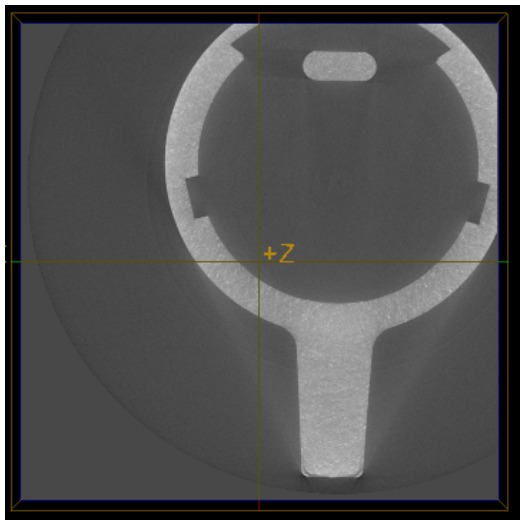


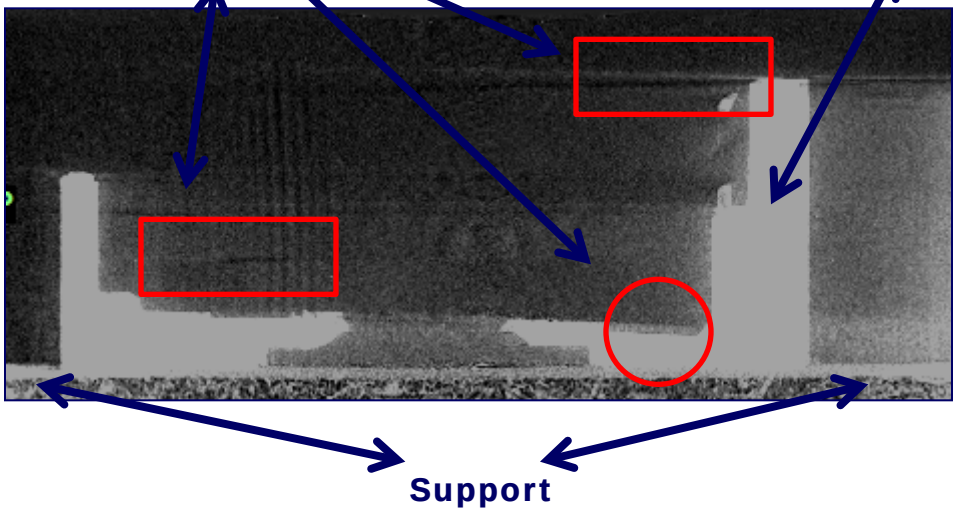
3D Volume low quality

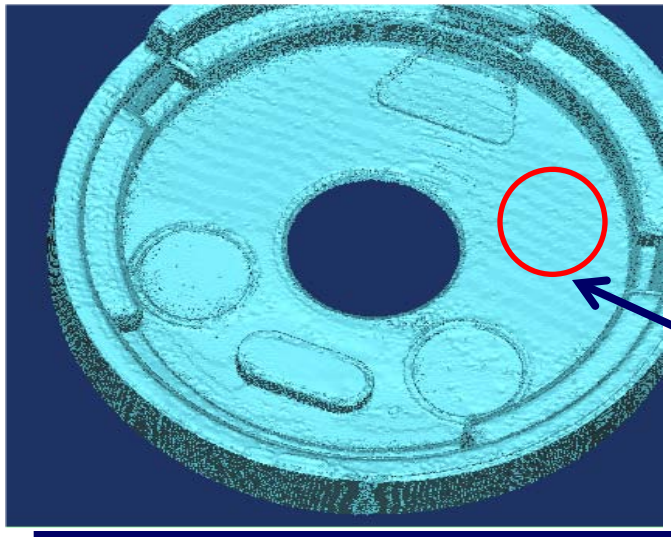


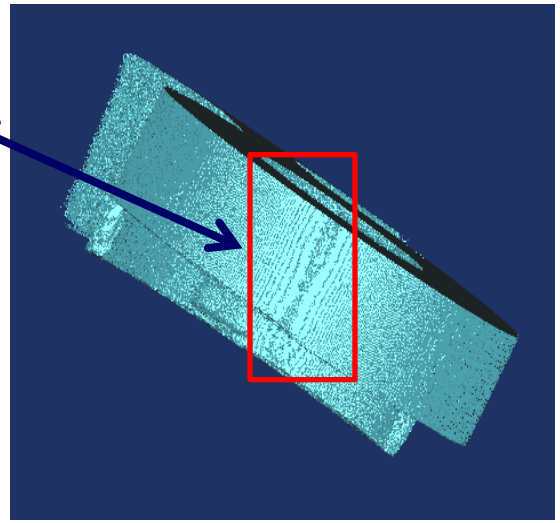
CT Image quality

Incorrect ROI

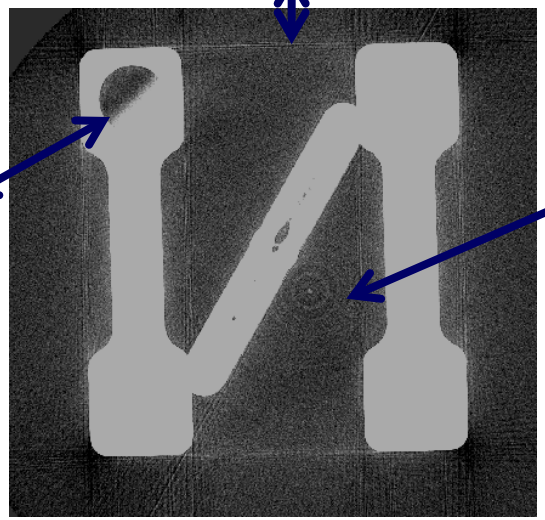


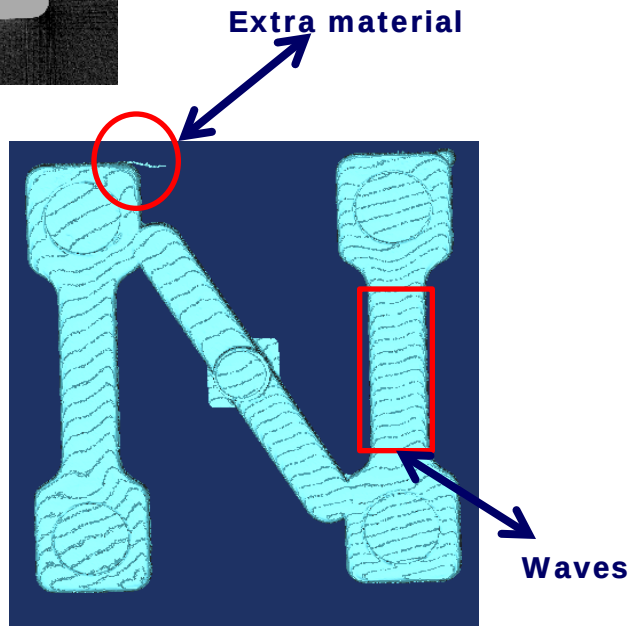


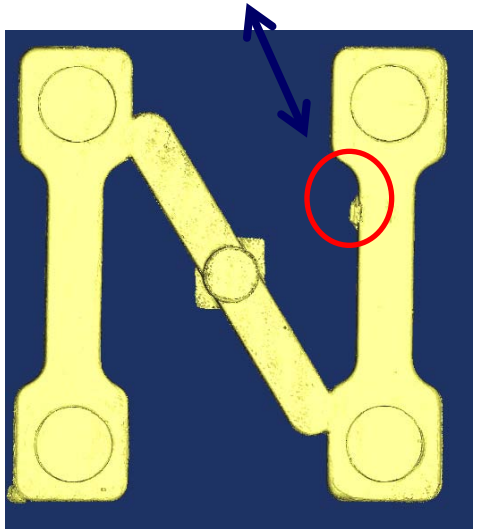




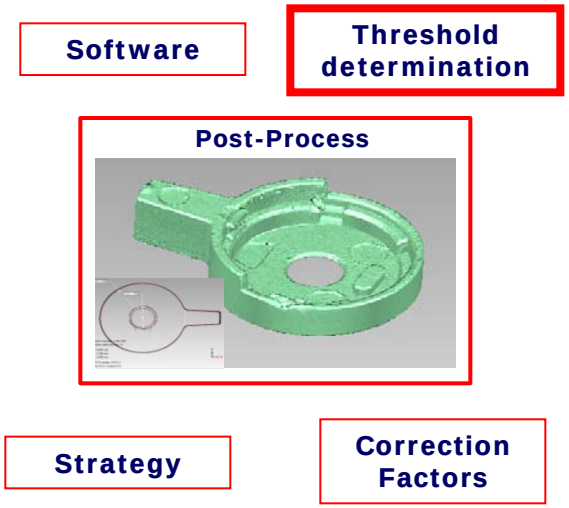
CT Image quality







Post-process: error sources



Threshold:

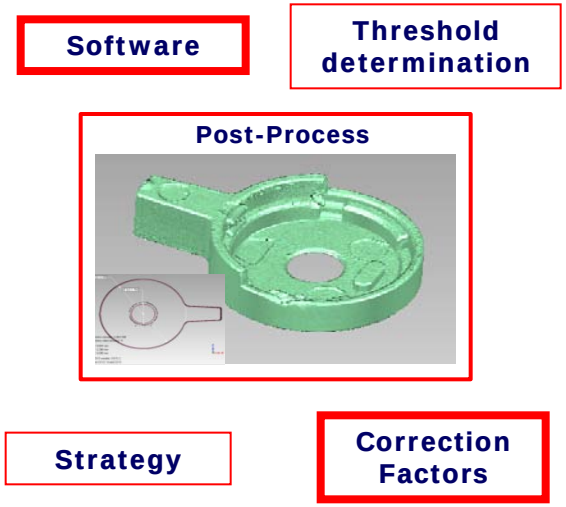
When the threshold value is reduced, D1 decreases.
When the threshold value is increased, D1 increases.
But D2 keeps constant.

A commonly chosen threshold for mono-material objects is the ISO50% value, representing the average between the peaks for background (light voxels) and material (dark voxels) on the histogram of all voxel model grey values → Not always the best option.

(Kim Kiekens, et al "A test object for calibration and accuracy assessment in x-ray CT metrology")

Each manufacturer uses its own algorithms.

Post-process: error sources



Software:

Each software has different options: filters, number of points, algorithms to create features etc. → Differences in the results

Correction factors:

Corrections can be made by different methods:

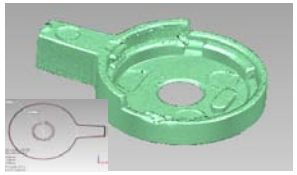
- Using CMM measurements as a reference to do a calibration threshold (ball bar).
- Mathematical factor scale correction.
- Mathematical compensation for diameters.

CT Evaluation

Software

Threshold determination

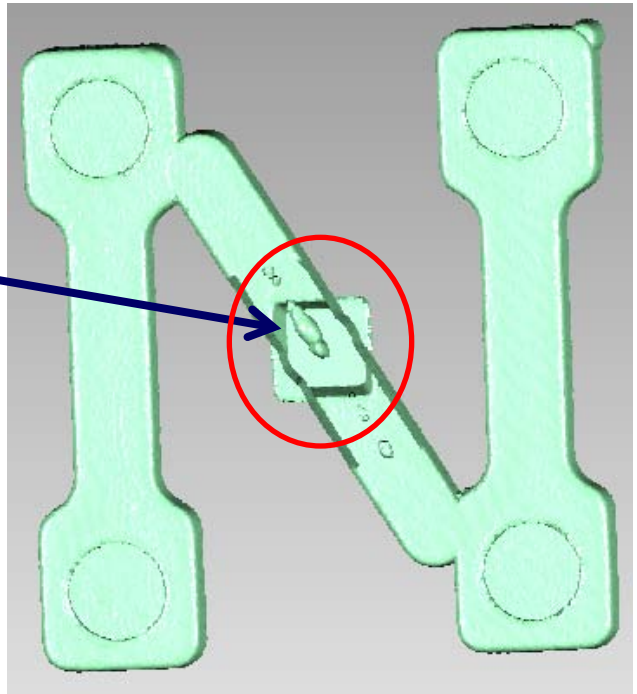
Post-Process

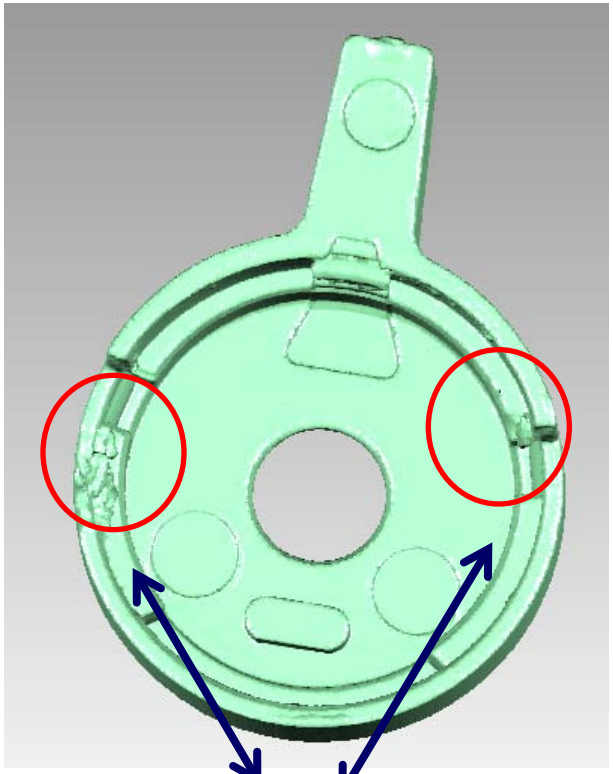


Strategy

Correction Factors

Work part defects





Work part defects

Outline

1. Introduction
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4. **Results**
5. Conclusions
6. Other interesting parts

4. Results

Dog Bone

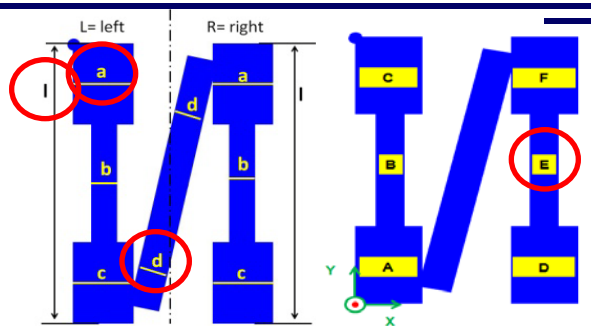
MEASURAND		DB1	DB2	DB3	DB4	DB5
L	l	11,802	11,842	11,794	11,823	11,867
	a	3,002	2,999	2,995	2,962	3,020
	b	1,518	1,498	1,513	1,451	1,517
	c	2,976	2,977	2,969	2,923	2,997
	d	1,350	1,343	1,356	1,289	1,360
R	l	11,826	11,845	11,815	11,844	11,882
	a	2,981	2,982	2,970	2,969	2,994
	b	1,523	1,504	1,528	1,463	1,525
	c	2,993	2,978	2,985	2,977	3,003
	d	1,350	1,342	1,352	1,293	1,363
T	A	0,990	0,989	0,994	0,936	1,015
	B	0,988	0,986	0,991	0,936	1,013
	C	0,990	0,981	0,986	0,943	1,015
	D	0,981	0,985	0,981	0,939	1,004
	E	0,977	0,979	0,978	0,935	1,004
	F	0,983	0,980	0,990	0,946	1,009

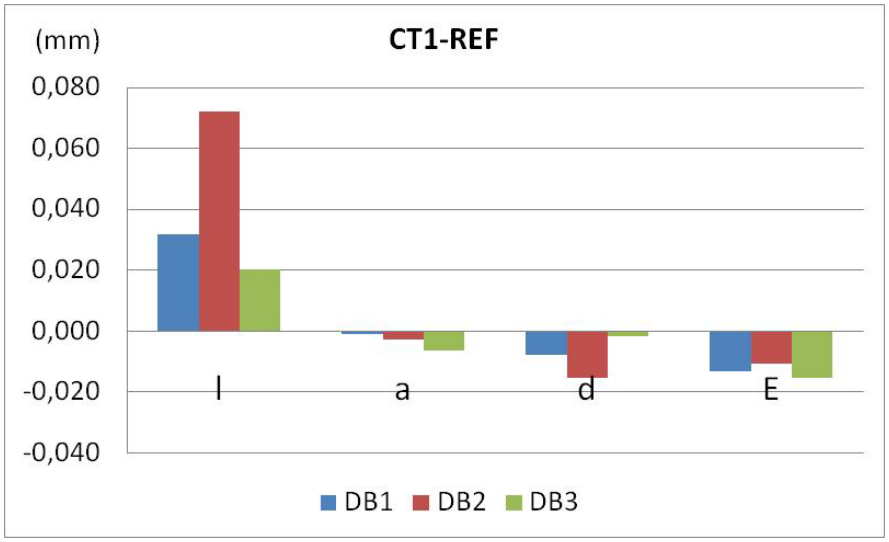
Toggle

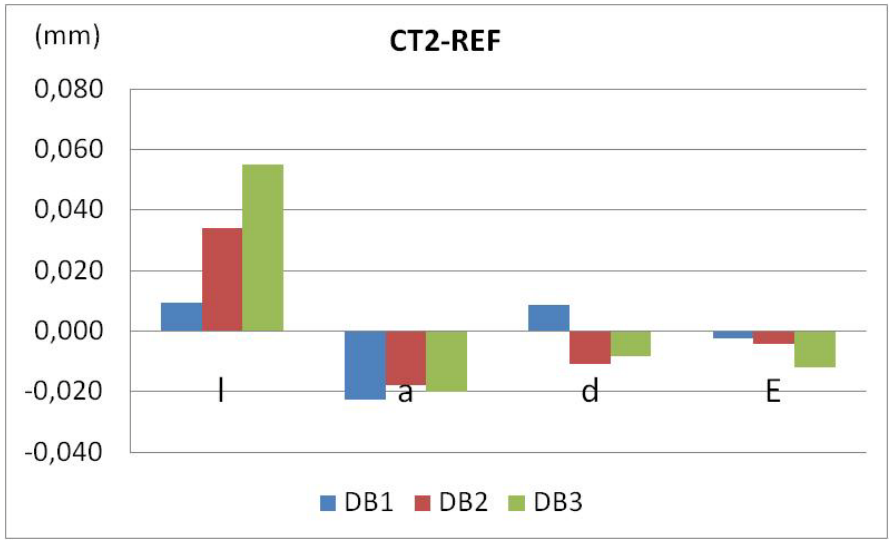
MEASURAND	T 1	T 2	T 3
H	0,392	0,396	0,379
d	1,514	1,533	1,512
D	5,52	5,459	5,494

4. Results

- Example: Dog bones 1, 2 & 3.
- CT1 and CT2 vs. reference values (OCMM).







- Deviations (CT vs OCMM) < 1% the reference dimension.
- Up to 4% for thickness in Z (OCMM limitations).
- Different parts → different results. Influences on the CT meas. process.
- Different machines → different results. Influences on the CT meas. process.

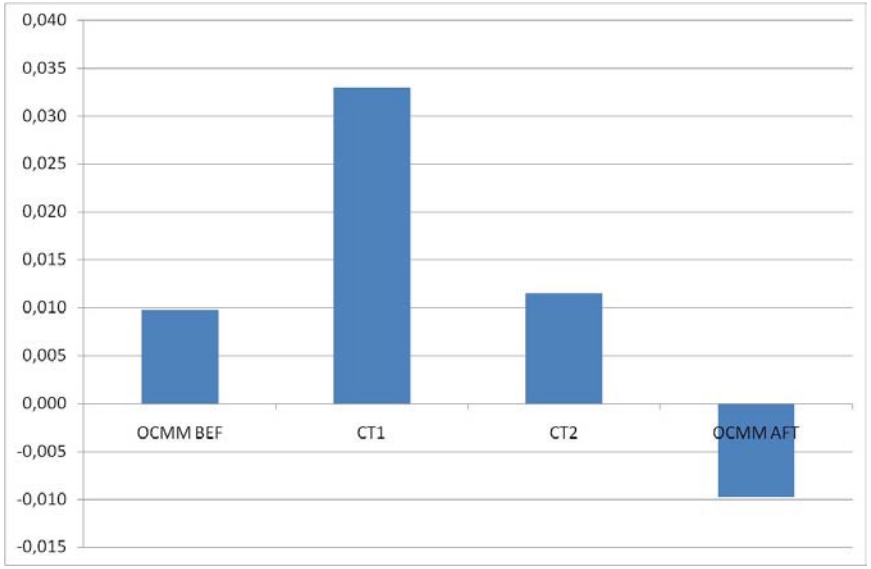
Results

- In spite of common measuring procedure, some differences still remain:
  - **OCMM** is able to measure the distance between edges on the thickness direction and not distance between planes.
- Further comparison with tactile is currently ongoing.

Results

- **Dimensional instability** of the material (plastic) → additional source of uncertainty.
  - All the parts were measured by a reference machine before and after their circulation around the two CT machines (for about 6 months).
  - Stability better than 5 µm for the toggle dimensions and better than 20 µm for the dog bone dimensions.

Deviations w.r.t. average OCMM values
Dog bone 1. L left. 20 µm stability



5. Conclusions

- Tactile measurements limitations for these parts (soft substrate surface) and OCMM limitations (thickness measurements).
- CT measuring techniques are feasible for a complete quality control of 3D micro moulded parts.
  - Non-contact.
  - Capability to provide morphological information such as suctions (i.e. valleys) on the parts' surfaces and voids inside the mouldings.
  - Ability to collect very complete point clouds from internal and external geometries and simultaneously gathering information on material properties.

Conclusions

- In order to improve the uncertainty of the results, **correction factors** (voxel size) still have to be applied to the measurements.
  - Factor cannot be based on the calibrated reference measurements of plastic parts. Maybe acceptable for toggles.
  - Evaluated on different calibrated parts measured in the same conditions as the actual measurements.

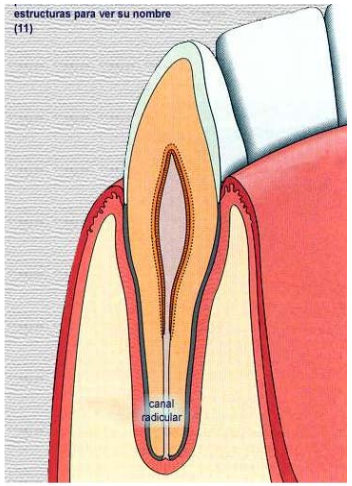
- Further characterization of error sources and **uncertainty calculation** → predominant and unknown uncertainty of measurand definition → more stable measurand for further analysis

Outline

1. Introduction
2. Materials and methods
3. Metrology using CT. Some considerations
4. Results
5. Conclusions
6. **Other interesting parts**

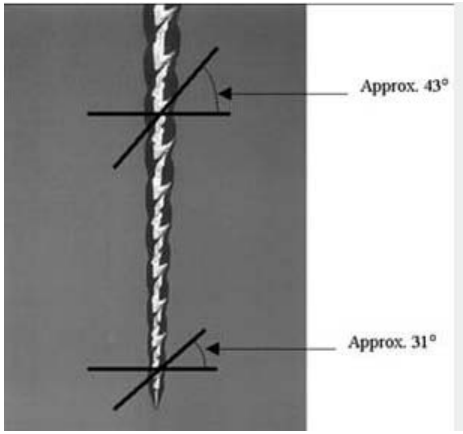
Endodontic file

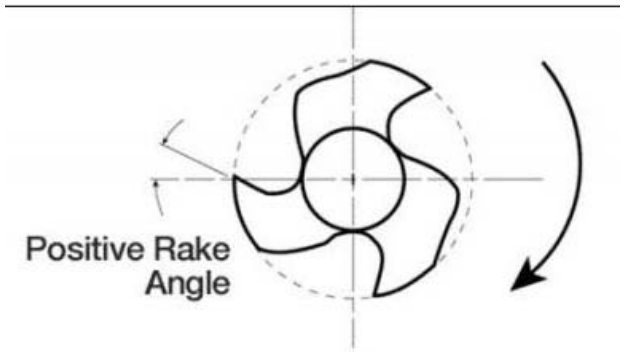
Instruments used to file the interior of the radicular root canal to eliminate germs and make it wide enough.



Variable geometry (angle and twist pitch length) along its axis
→ Difficulties to be measured by traditional CMMs.

Dimensions of interest

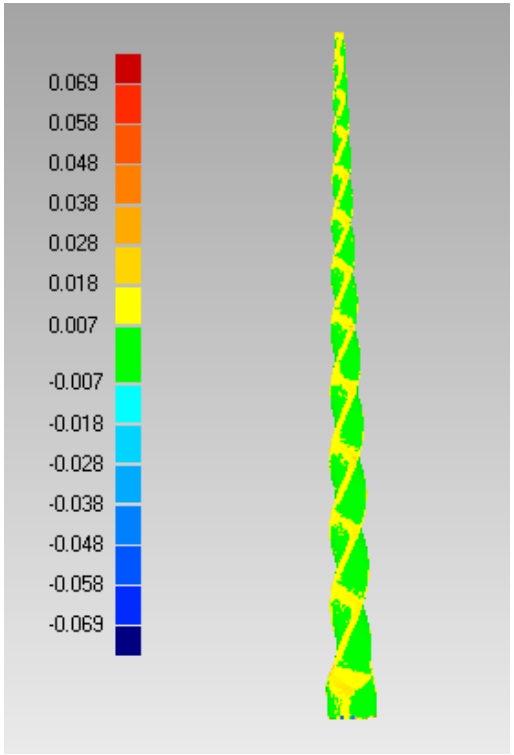


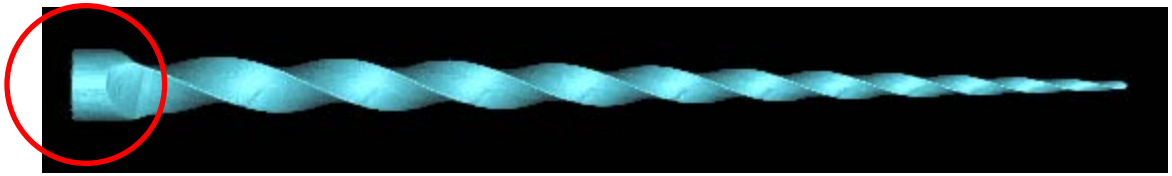


Endodontic file

Comparison to CMM, roundness machine, profilometer...

CT more adequate





Threshold calibration at the cilinder using CMM measurements as a reference.

Application of CT Scanning in Industry
Danish Technological Institute

Taastrup, Denmark, 31st May 2011

Measurement of micro moulded parts by Computed Tomography

Universidad Zaragoza

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