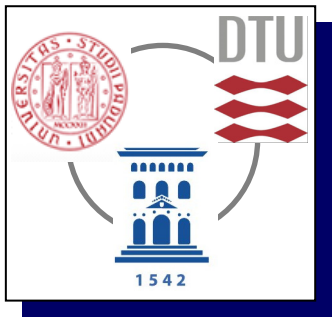
Application for Computed Tomography in Metrology for Micro Manufacturing

G. Tosello[1], J. A. Yagüe-Fabra[2], S. Carmignato[3], H.N. Hansen[1]

[1]*DTU Mechanical Engineering, Technical University of Denmark, DK-2800, Kgs. Lyngby, Denmark*

[2]*I3A, University of Zaragoza, E-50018 Zaragoza, Spain*

[3]*DTG, University of Padova, I-36100, Vicenza, Italy*



Danmarks Tekniske Universitet DTU

Universidad Zaragoza 1542

Università degli Studi di Padova

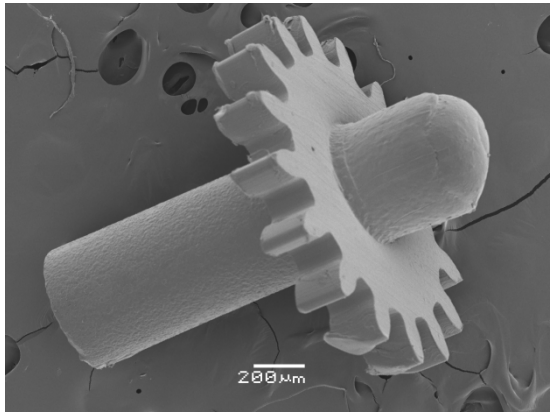
Guido Tosello
Hans Nørgaard Hansen

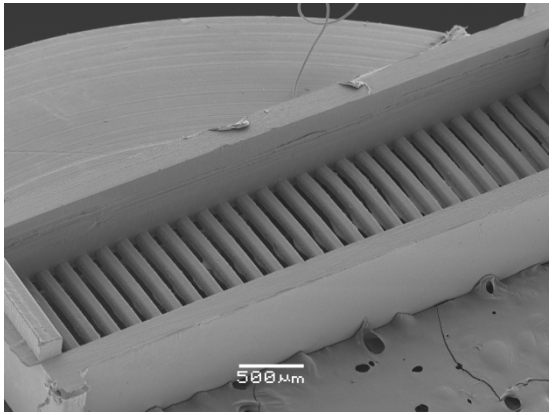
José Yagüe-Fabra

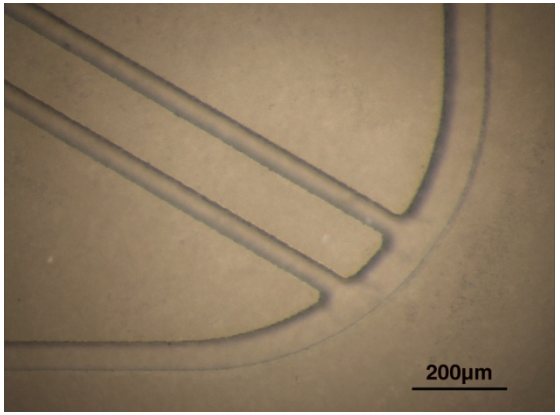
Simone Carmignato

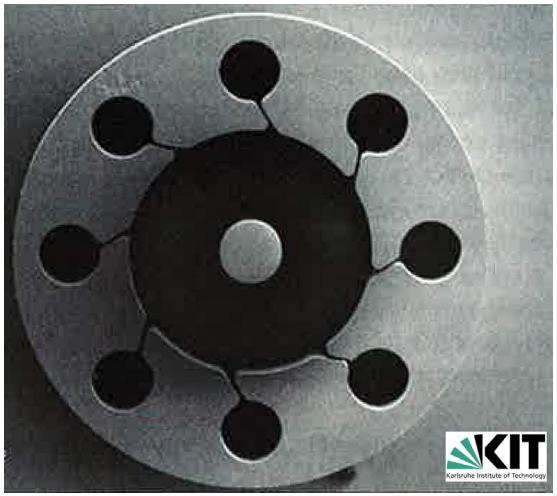
DTU Mechanical Engineering
Department of Mechanical Engineering

Micro Injection Moulding (µIM)



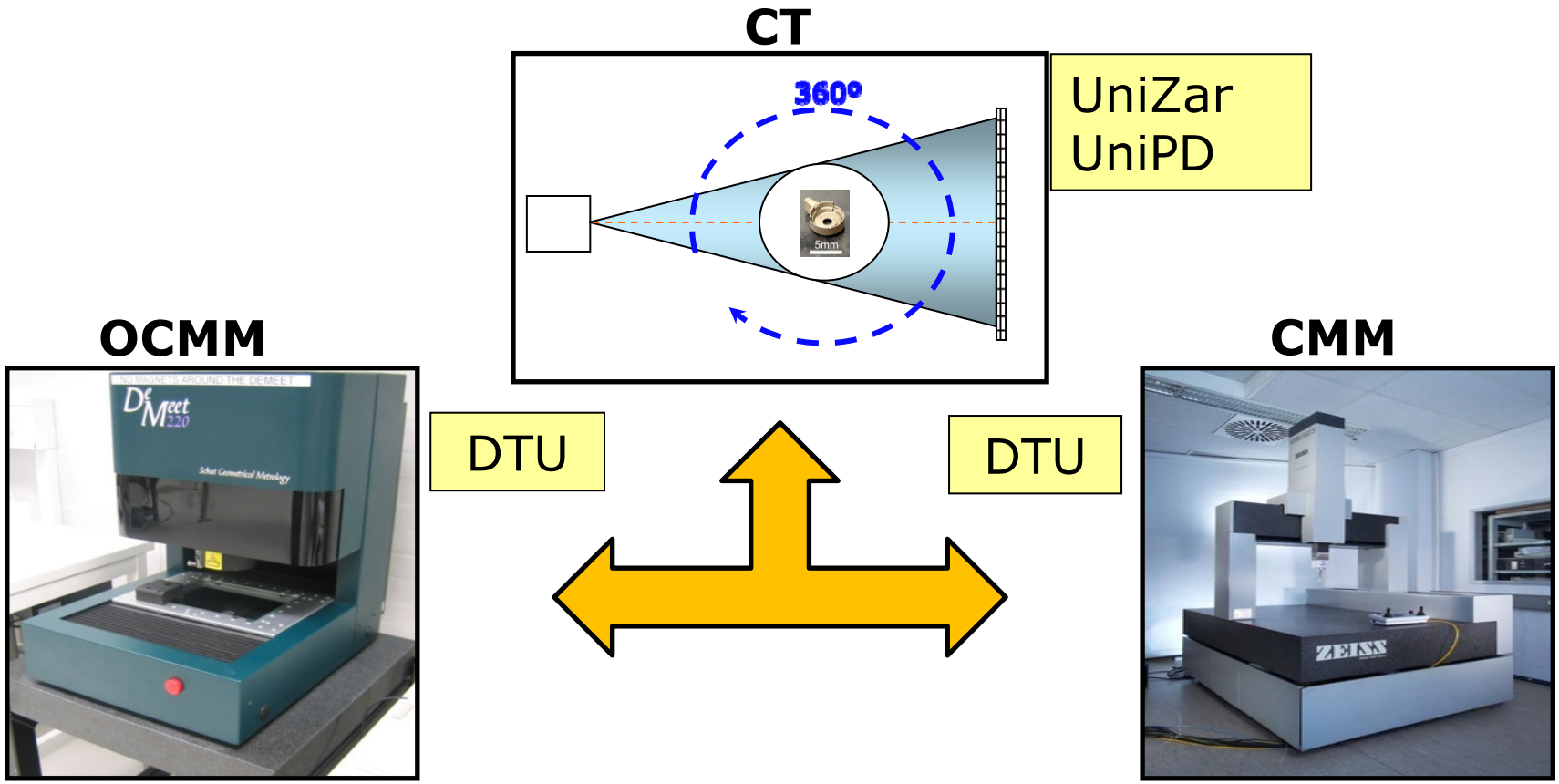






Objectives

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



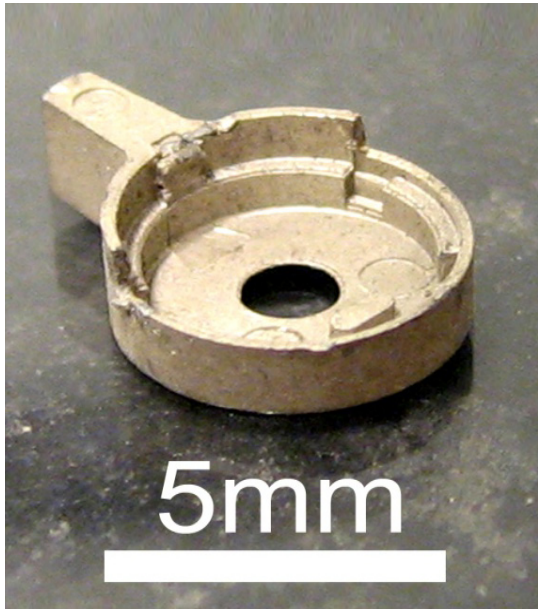
Outline

1. **Introduction**
2. **Materials and methods**
3. *CT results - imaging*
4. *CT results - measurements*
5. *Conclusion*
6. *Outlook / Work in progress*

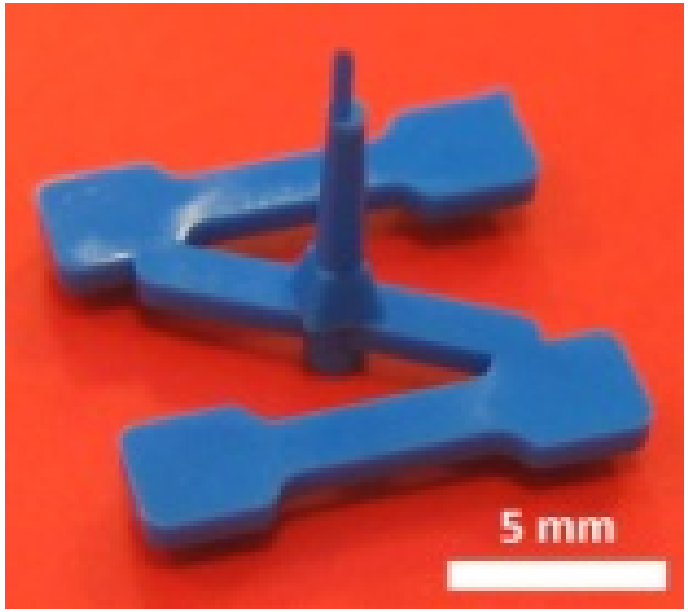
Introduction

- Accuracy and time demands tighter and tighter → **smaller mechanical parts** are characterized by smaller tolerances to be verified
- **Computed Tomography** (CT) metrology techniques are more and more applied for micro-parts geometrical verification:
  - Advantages: non-contact, dense scanning, capability of measuring both internal and external geometries simultaneously, NDT
  - However: challenge to obtain high accuracy measurement results, i.e. with U/T<10%-20%

Materials and methods
Micro injection moulded parts



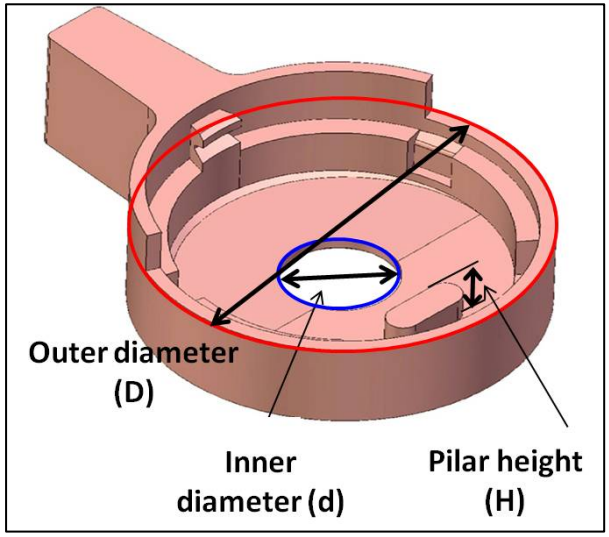
Toggle
Hearing aid application
Liquid crystal polymer (LCP)
Part mass: 35 mg



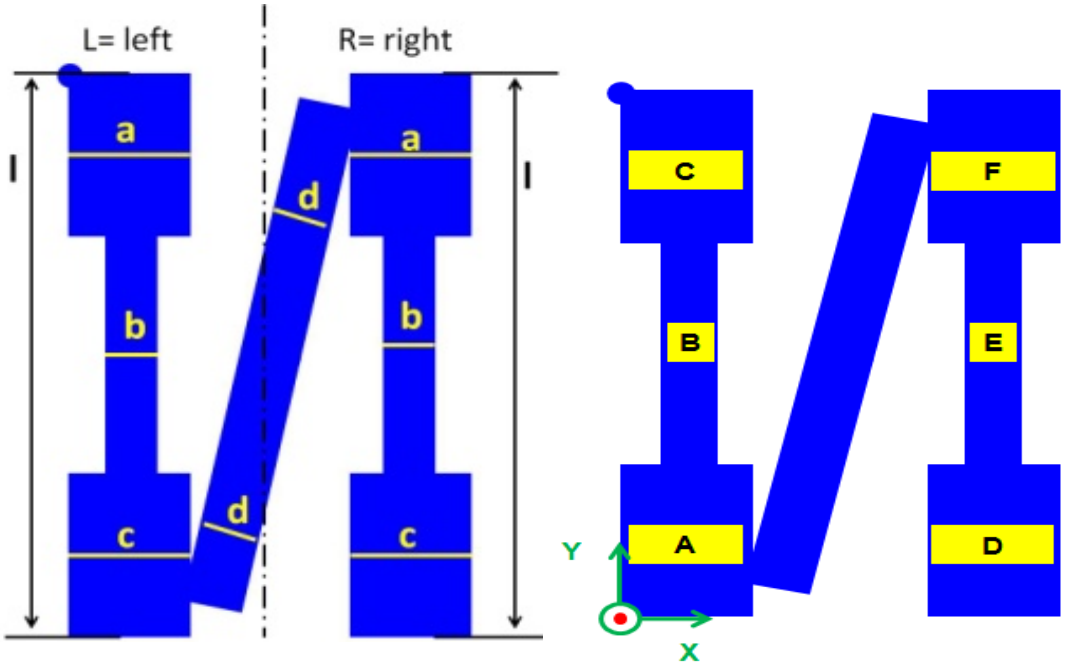
Micro Dog Bone
Micro mechanical material tensile testing
Polyoxymethylene (POM)
Part part: 35 mg

Dimensions

- Both internal and external geometries
  - part thickness
  - internal diameter
  - external diameter
  - part length
- 3 different measuring techniques: CT, TCMM, and OCMM



Length **Thickness**



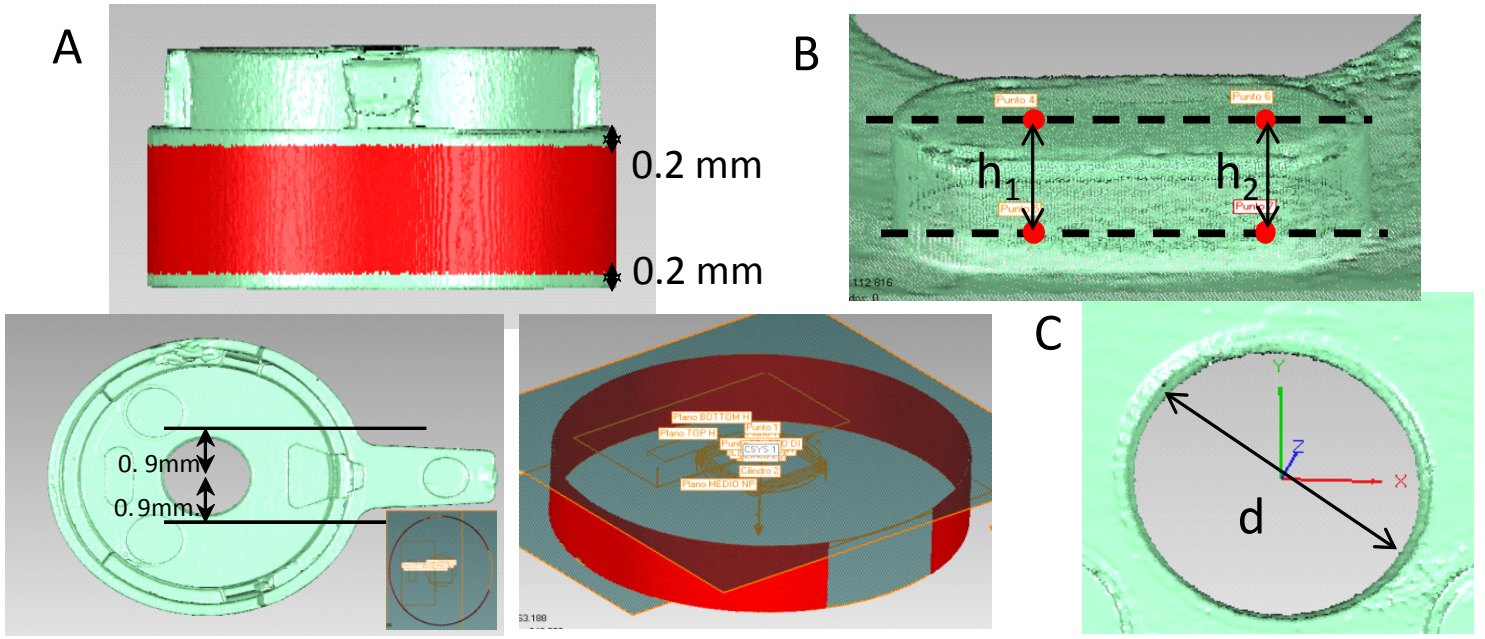
Measuring procedure – Toggle

- Different measuring systems
- Common measurand definition
- Comparison of different measuring results

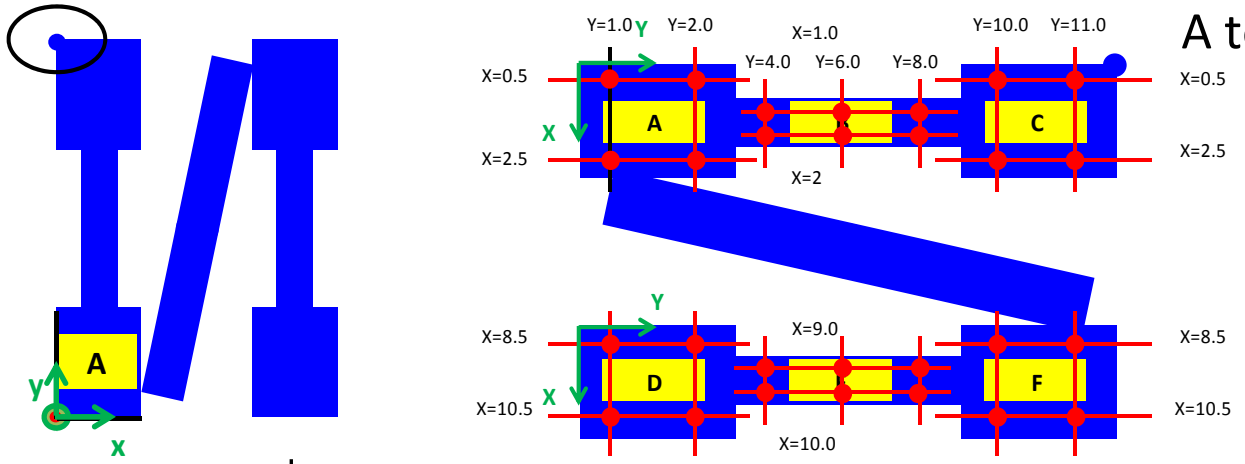
D=5.400 ± 0.030 mm

d=1.550 ± 0.020 mm

H=0.380 ± 0.030 mm



Measuring procedure – Dog bone

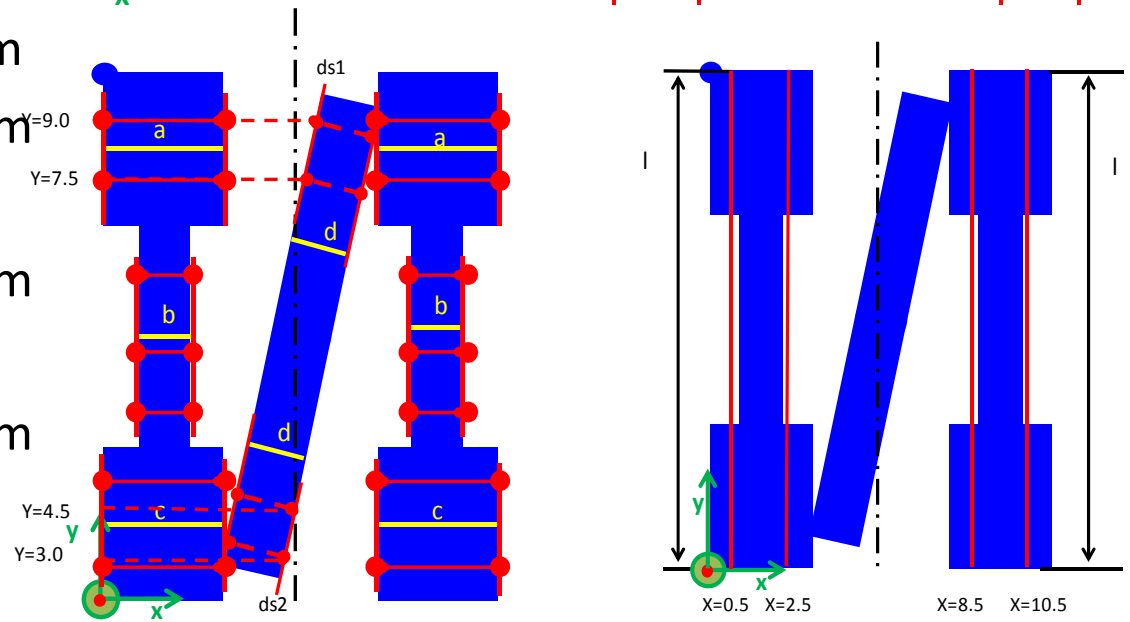


A to F = 1.000 mm
± 0.020 mm

a,c = 3.000 mm
± 0.030 mm

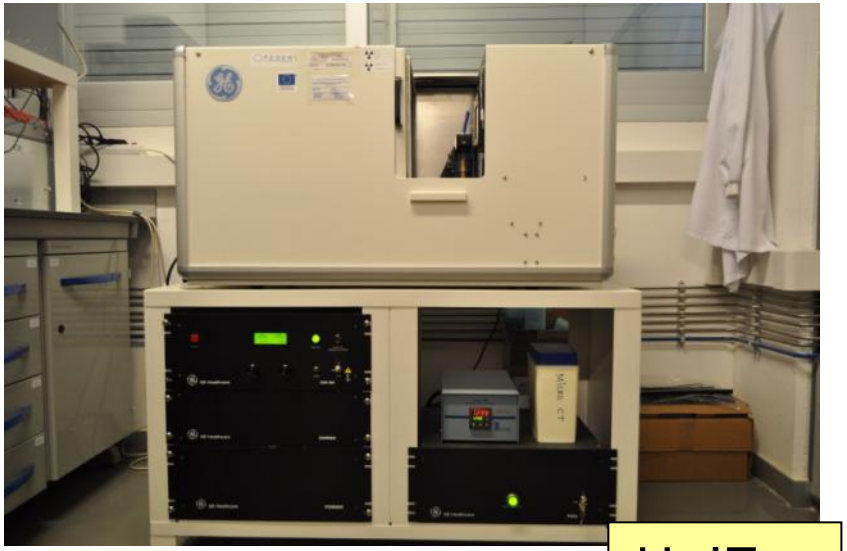
b = 1.500 mm
± 0.020 mm

d = 1.350 mm
± 0.020 mm



L = 11.800 mm
± 0.030 mm

Measuring machines: CT1



UniZar

- 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

- *S. Ontiveros, J.A. Yagüe-Fabra, R. Jiménez, G. Tosello, S. Gasparin, A. Pierobon, S. Carmignato, H.N. Hansen (2012) Dimensional measurement of micro-moulded parts by computed tomography, Measurement Science and Technology, 23 125401 (9pp) doi:10.1088/0957-0233/23/12/125401.*

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

UniPD

- *S. Ontiveros, J.A. Yagüe-Fabra, R. Jiménez, G. Tosello, S. Gasparin, A. Pierobon, S. Carmignato, H.N. Hansen (2012) Dimensional measurement of micro-moulded parts by computed tomography, Measurement Science and Technology, 23 125401 (9pp) doi:10.1088/0957-0233/23/12/125401.*

Measuring machines: OCMM and TCMM

DTU

- Optical CMM: 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.*

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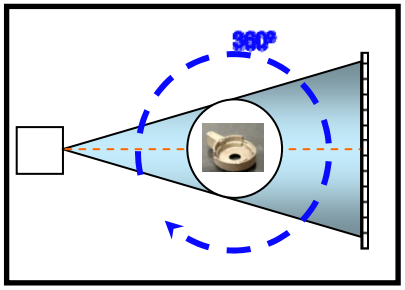
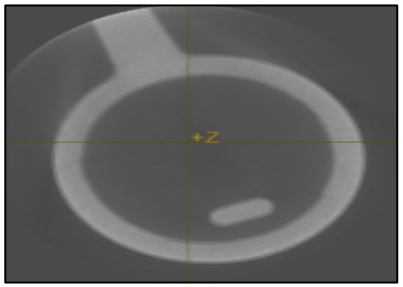
3. CT Metrology: Process

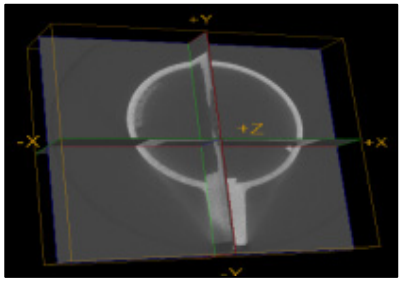
Work Piece



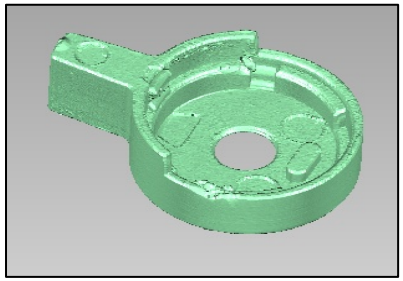
Scanning



Slices

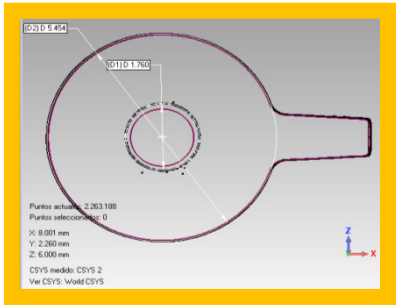


Reconstruction



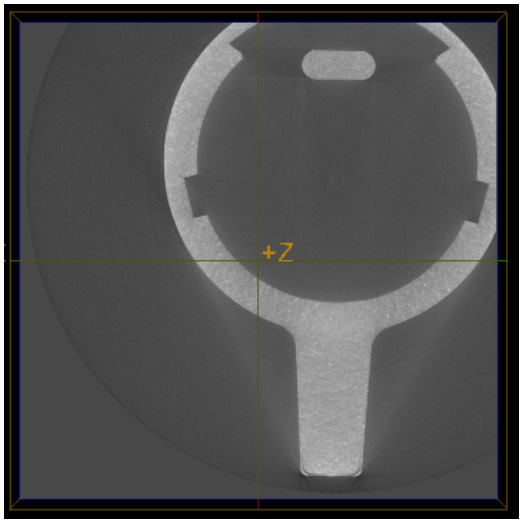
Surface Extraction

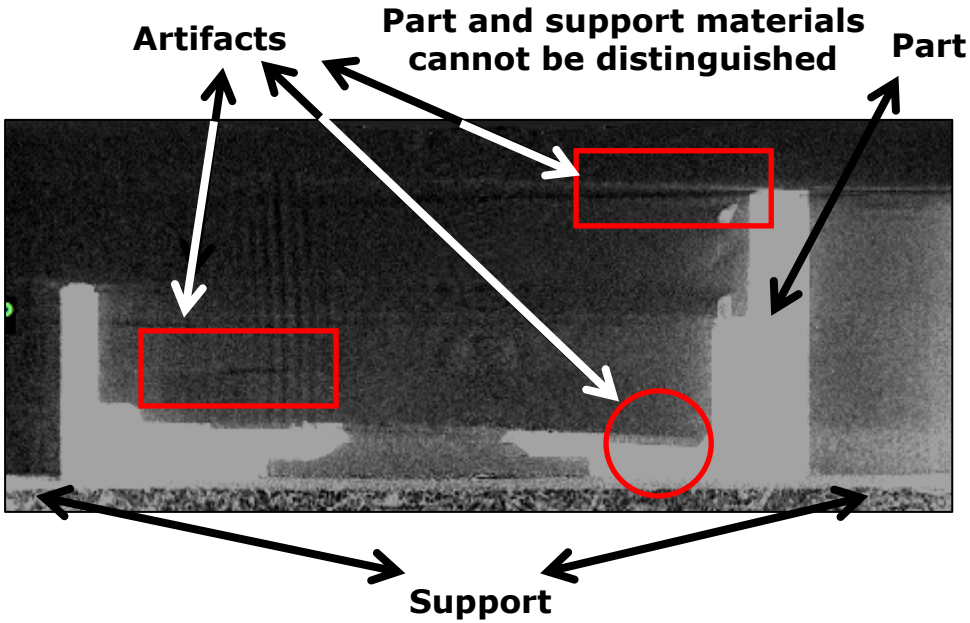
Correction factors

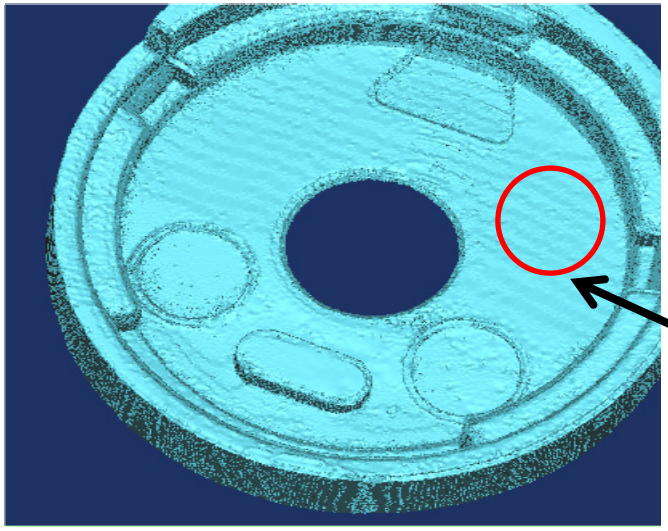


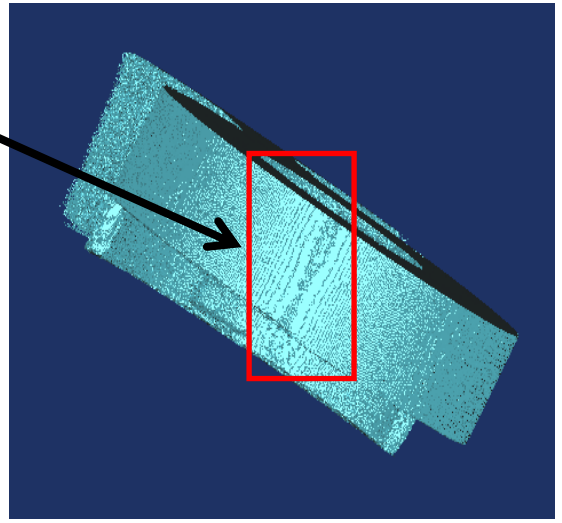
Evaluation

CT Image quality

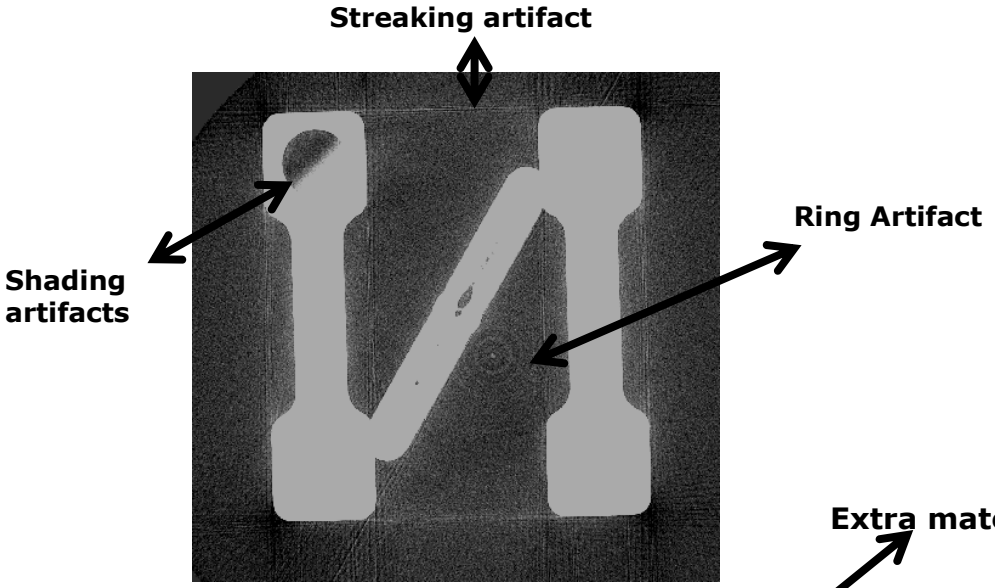


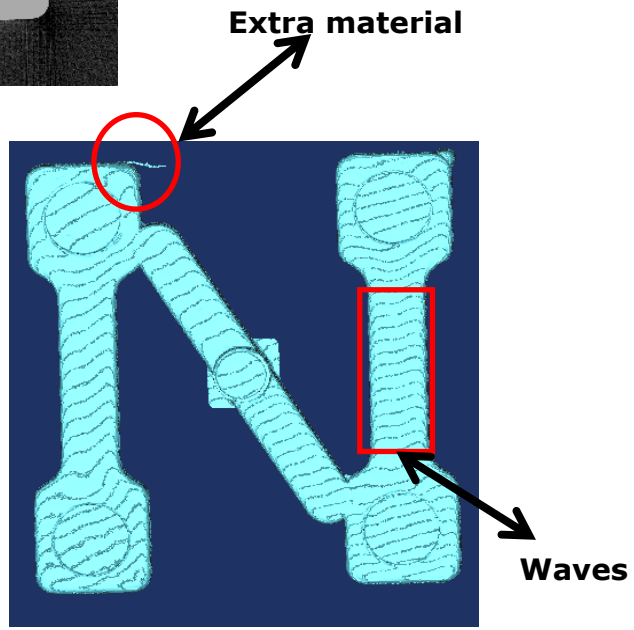


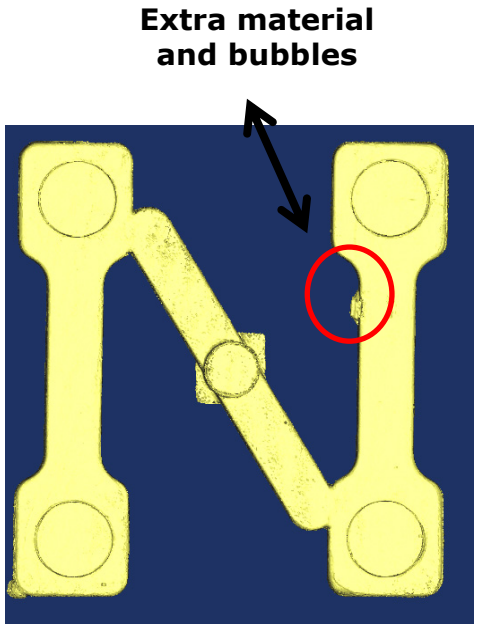




CT Image quality





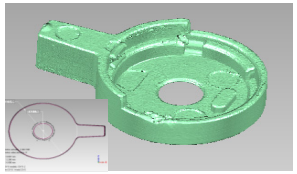


CT Evaluation

Software

Threshold determination

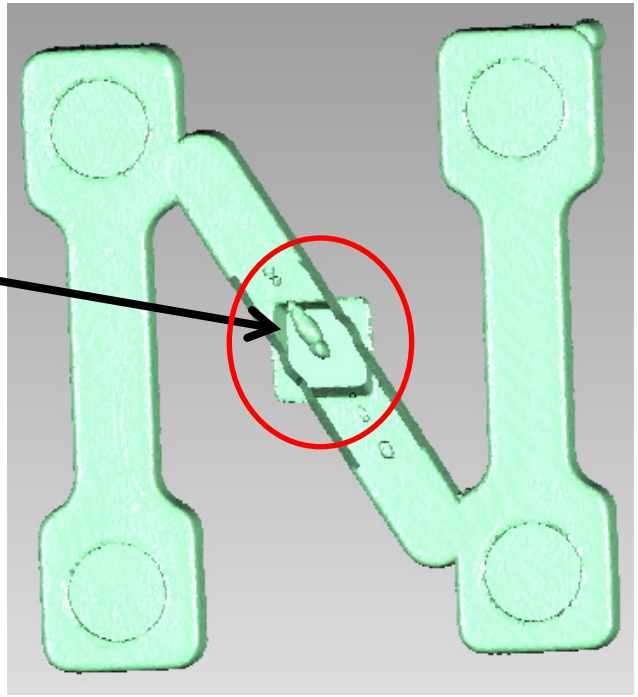
Post-Process

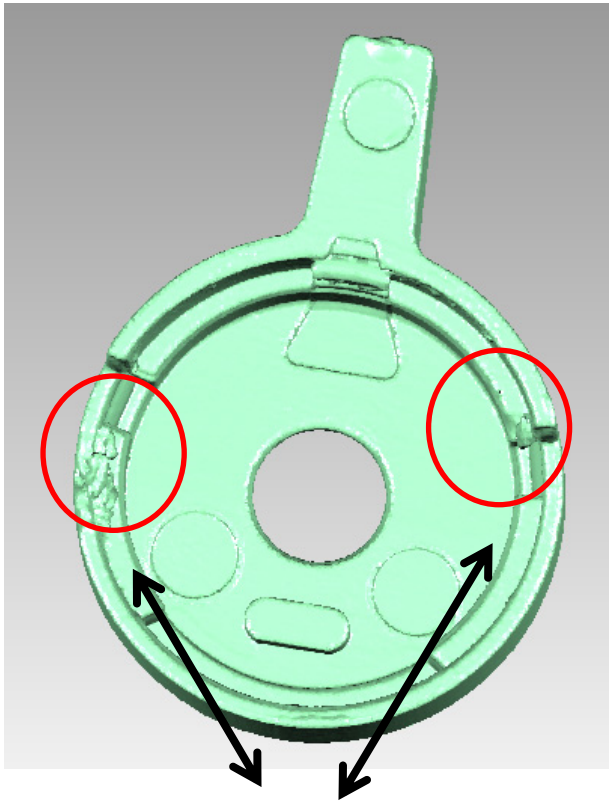


Strategy

Correction Factors

Work part defects





Work part defects

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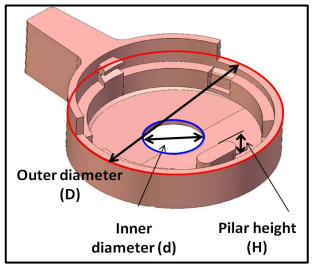
Correction Process 1
Features with external and internal dimensions

1. Determine the ratio between Inner Diameter (ID) and Outer Diameter (OD) of the reference measurement. This ratio does not depend on the scale factor.



$$\text{Ratio} = \frac{\text{OD}}{\text{ID}}$$

2. Adjust the threshold in the CT measurements and calculate the ratio, repeat this process until value calculated in step 1 is obtained.

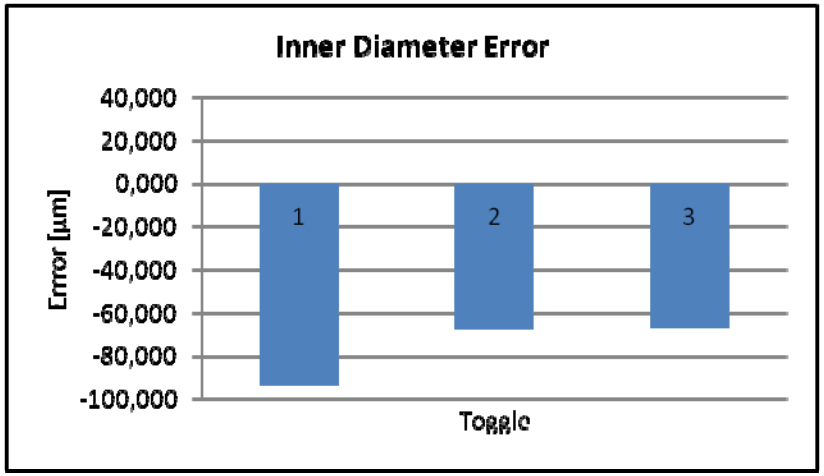
3. Once obtained the ratio in the step 2, calculate the scale factor.

$$\text{Scale Factor} = \frac{L_{CT}}{L_{Reference}}$$

4. Apply the scale factor to the CT measurements.

Results – Toggle

Before Correction

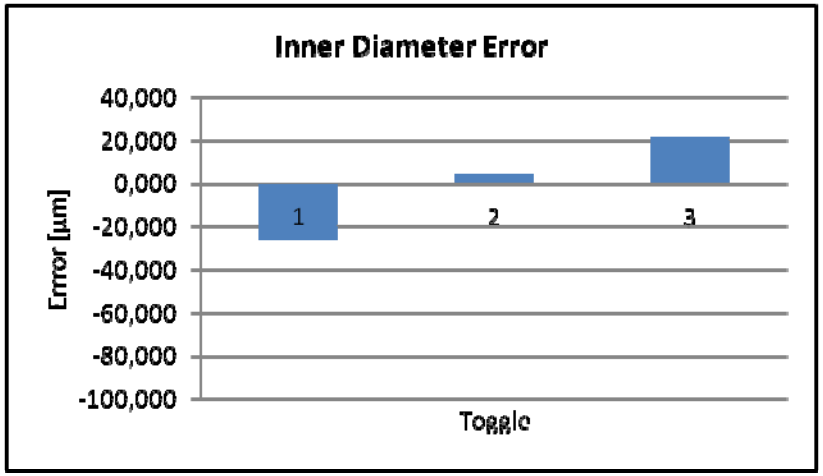


Maximum Error: -93 µm

Minimum Error: -66 µm

Average Error(abs): 75 µm

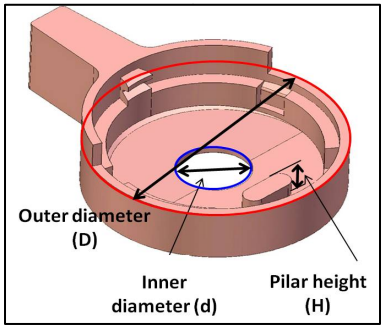
After Correction



Maximum Error: -25 µm

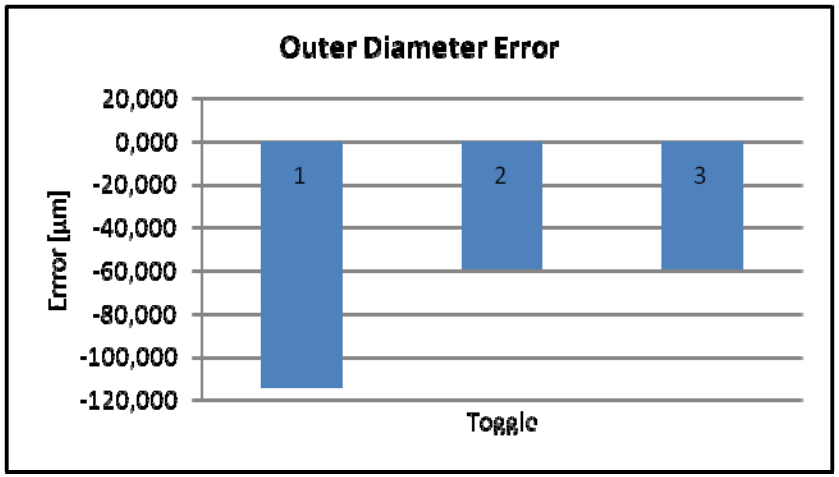
Minimum Error: -21 µm

Average Error(abs): 17 µm



Results – Toggles

Before Correction

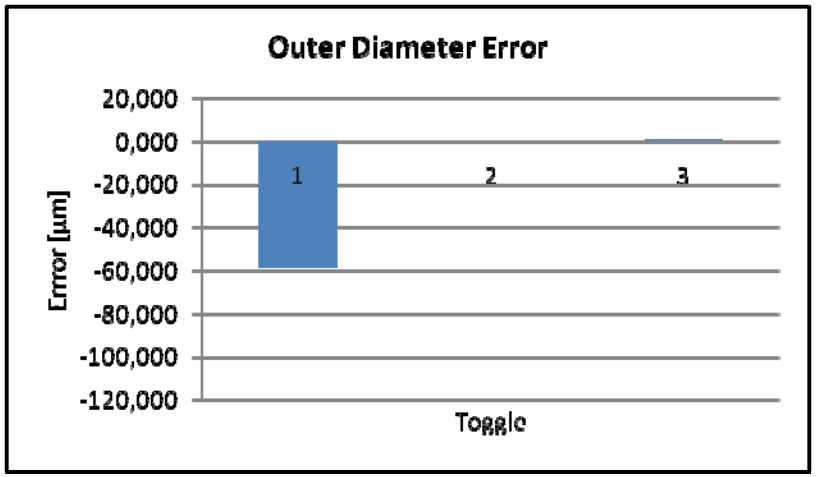


Maximum Error: -114 µm

Minimum Error: -59 µm

Average Error(abs): 77 µm

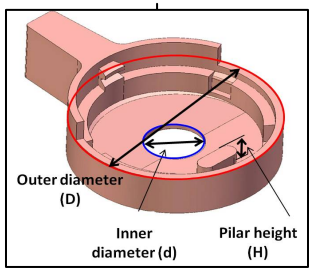
After Correction



Maximum Error: -58 µm

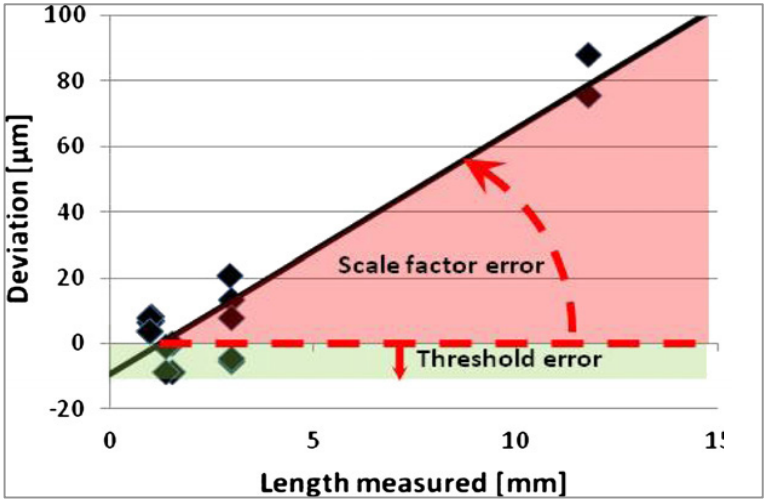
Minimum Error: 0.4 µm

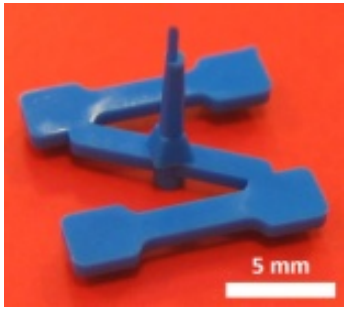
Average Error(abs): 19 µm



Correction Process 2
Features with external dimensions

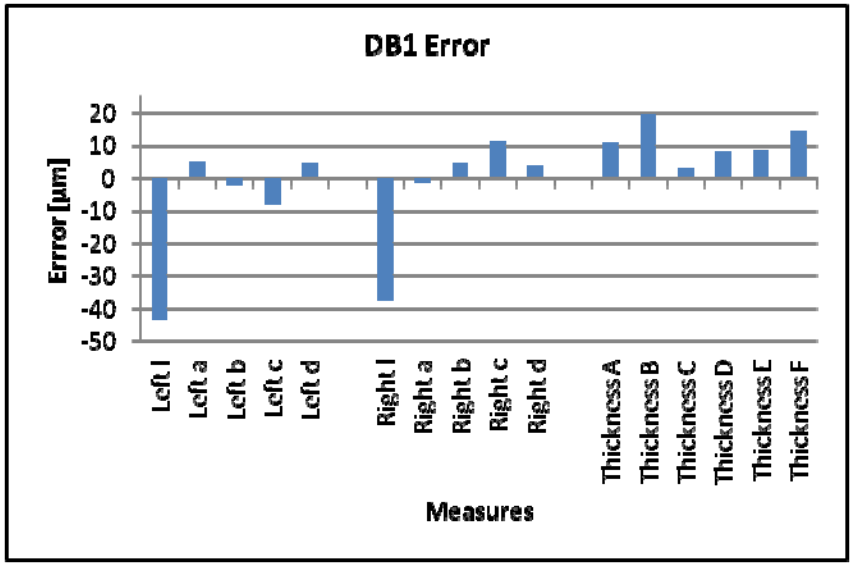
1. Make the surface extraction at ISO 50% and measure the workpiece
2. Calculate the deviations of the CT measurement results from the reference calibrated values
3. Find the slope of the line that passes through the error points
4. Apply the equation of the slope to the measurements made at step 1





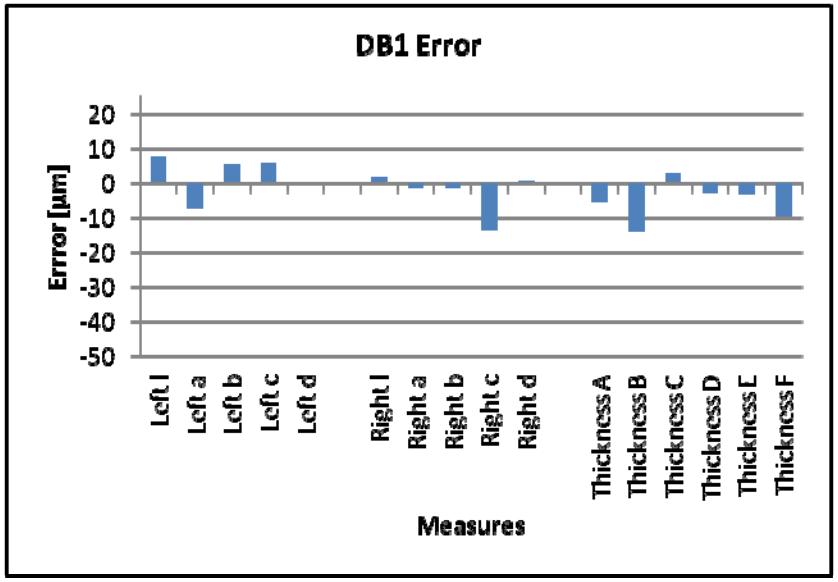
Results – Dog Bones

Before Correction

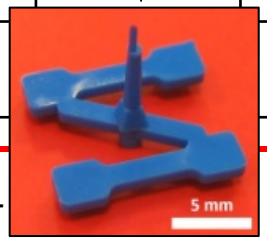


[µm]	Left Side	Right Side	Thickness
Maximum Error	-43	-37	19,3
Minimum Error	4,8	11,3	2,8
Average Error(abs)	12,2	11,6	10,6

After Correction

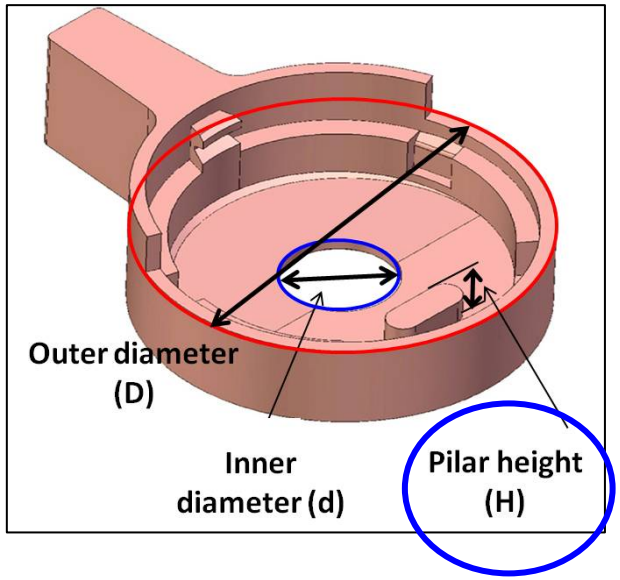


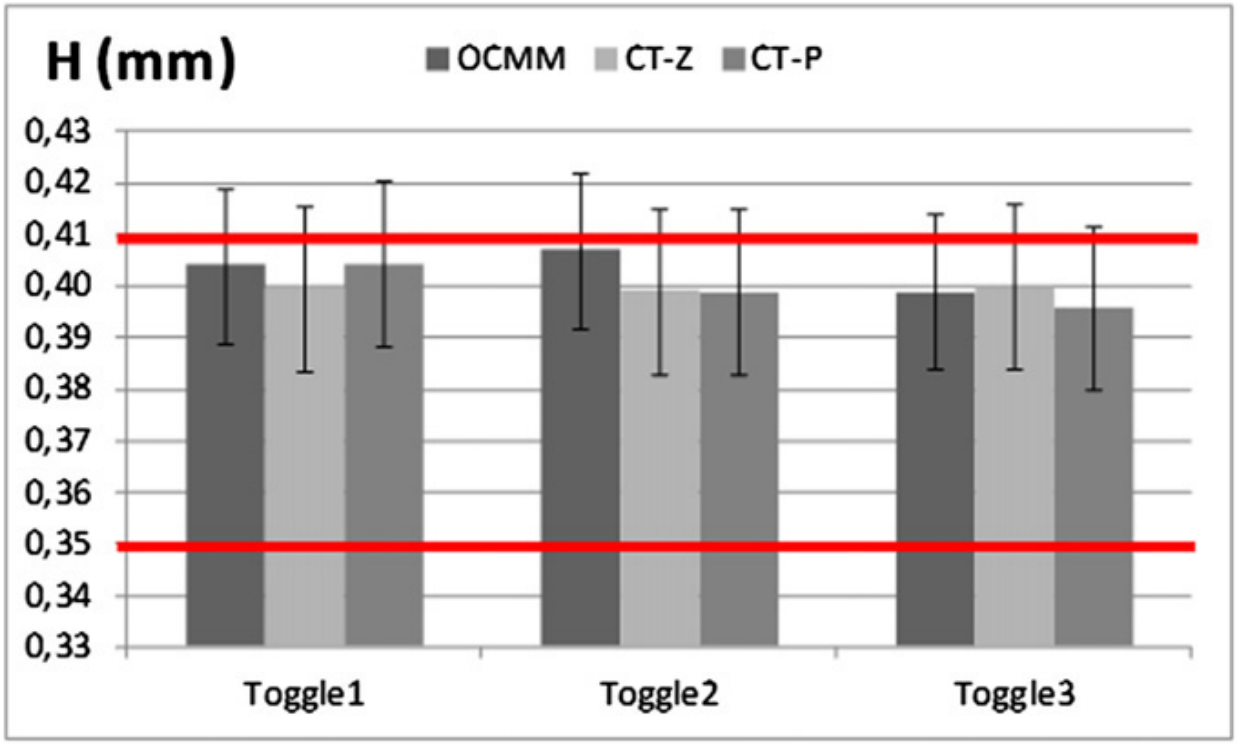
[µm]	Left Side	Right Side	Thickness
Maximum Error	7,4	-13.3	-13.7
Minimum Error	-6,9	1,6	2,8
Average Error(abs)	5,1	3,5	5,9



Measurements results comparison CT vs. OCMM

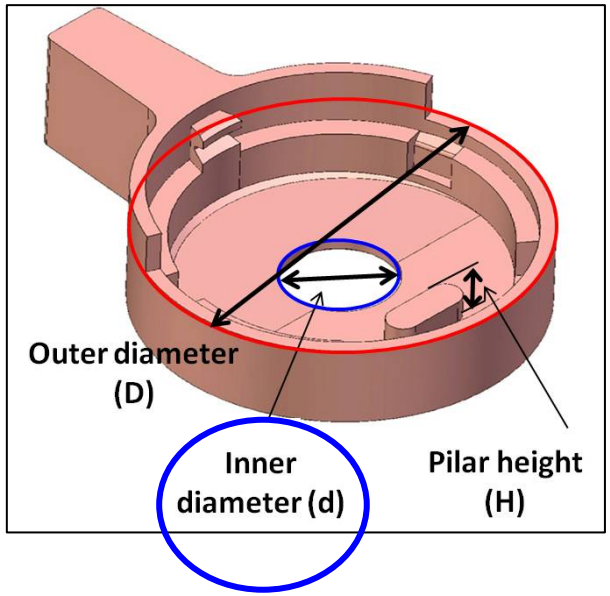
- H=0.380 ± 0.030 mm

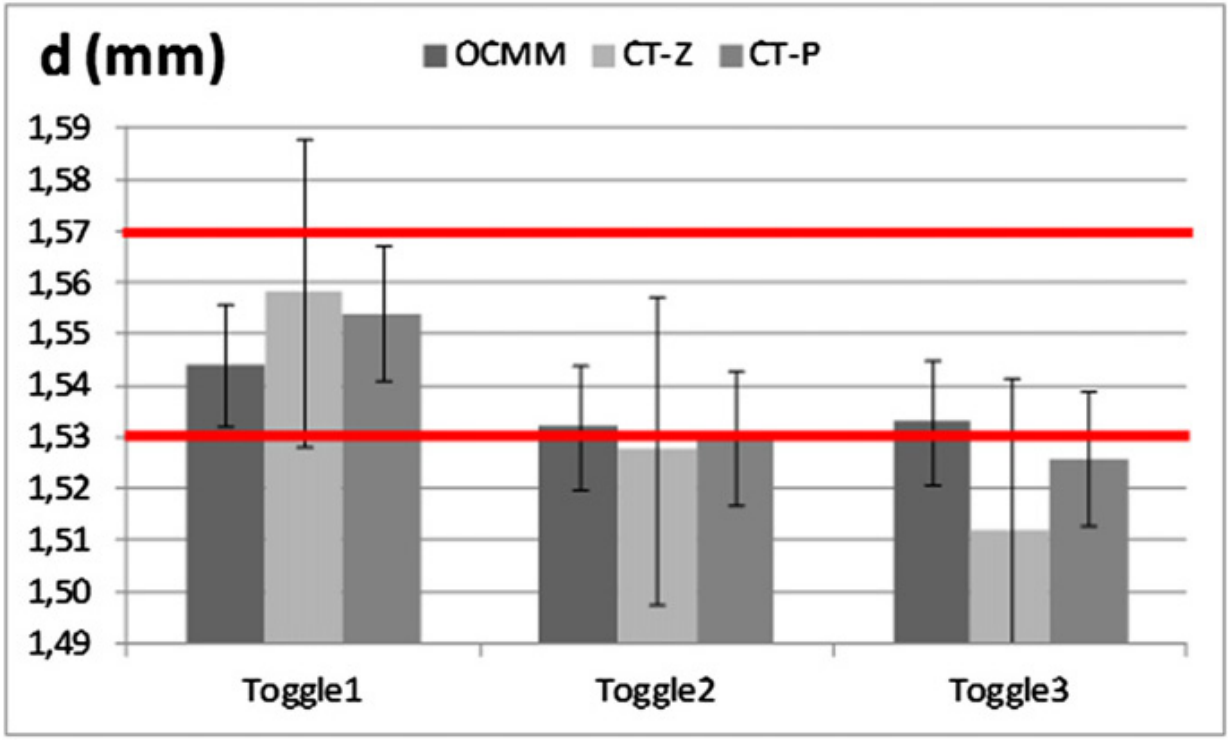




Measurements results comparison CT vs. OCMM

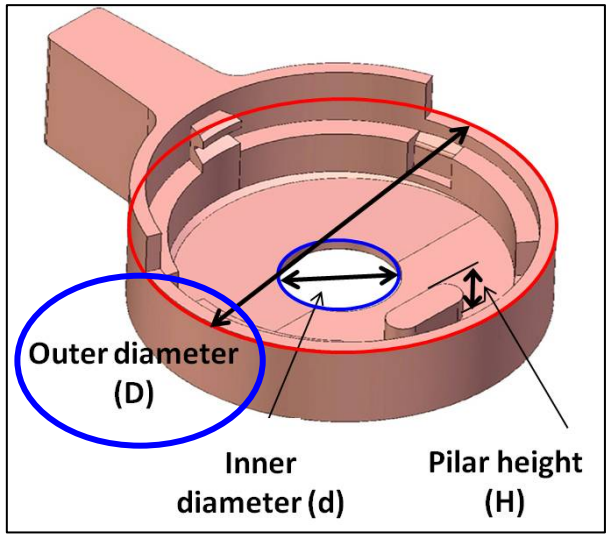
- d=1.550 ± 0.020 mm

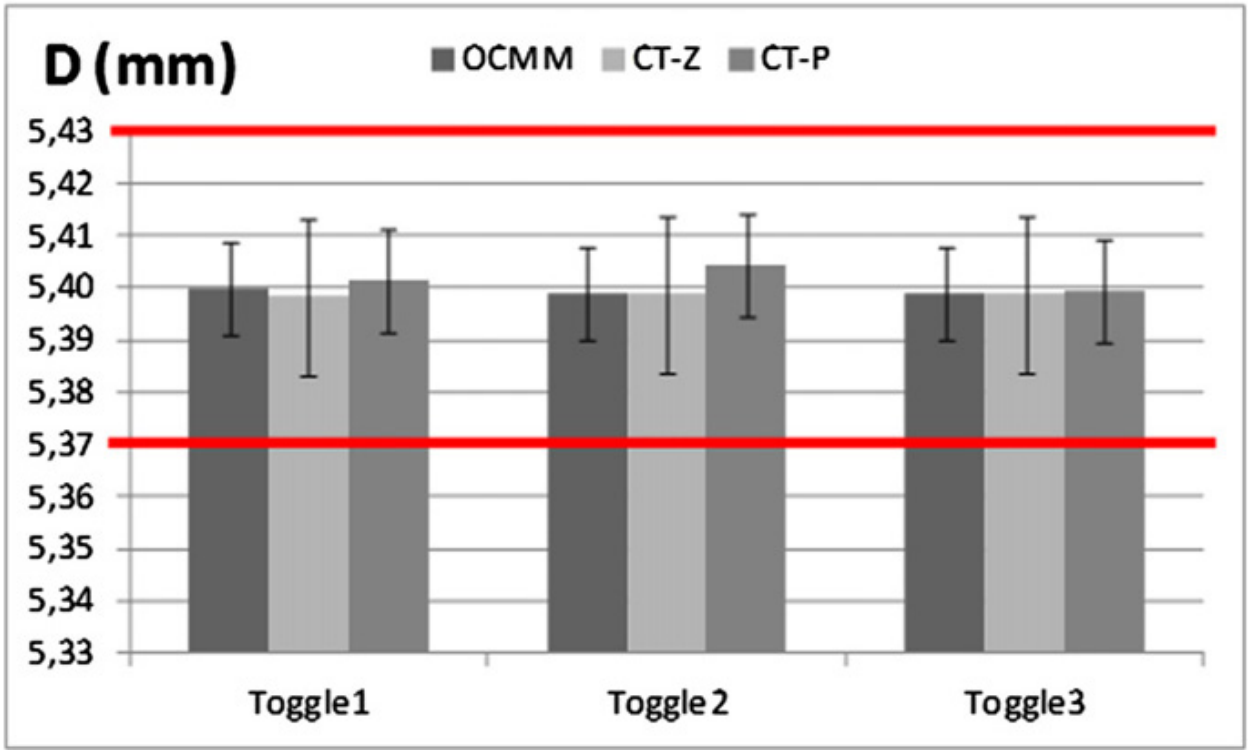




Measurements results comparison CT vs. OCMM

- D=5.400 ± 0.030 mm





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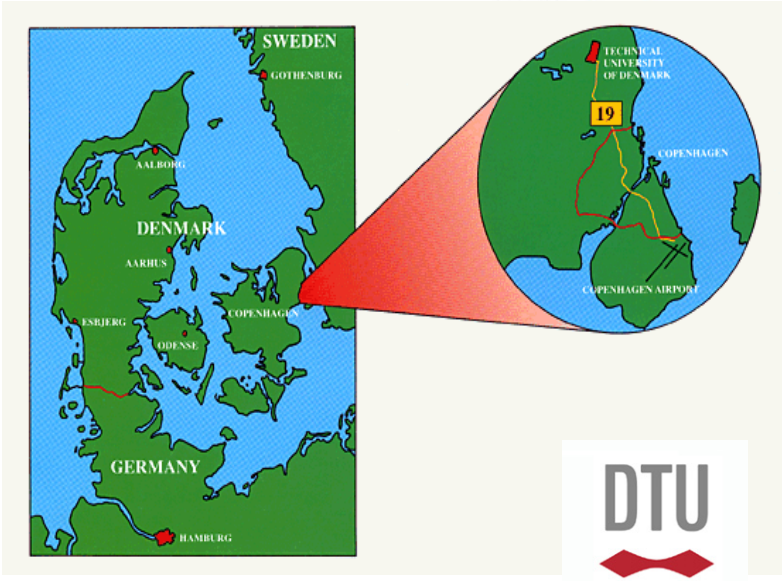
2. *Materials and methods*
3. *CT results - imaging*
4. *CT results - measurements*
5. **Conclusion**
6. **Outlook / Work in progress**

Conclusion

- CT measuring techniques are feasible for a complete quality control of 3D micro moulded parts
- Capability to provide morphological information such as sink marks on the surface and voids inside the mouldings
- Ability to collect comprehensive point clouds from internal and external geometries and simultaneously gathering information on material properties
- Correction strategies effective to improve measurement accuracy

Department of Mechanical Engineering
Section of Manufacturing Engineering
Micro/Nano and Precision Manufacturing

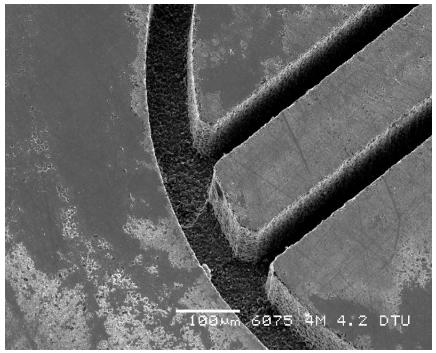


- **Department of Mechanical Engineering**
  - 6 sections, administration and workshops
  - Scientific personnel = 107 (2012)
  - Technical & Administrative = 85 (2012)
  - PhD students graduates = 23 (2011)

- **Section of Manufacturing Engineering**
  - **Micro/Nano and Precision Manufacturing (MPP)**
  - Scientific personnel = 19 + Technical personnel = 23 (2013)
  - PhD students = 18 (2013)
  - MSc students graduates = 15-20 / year
  - BSc students graduates = 5-10 / year
  - MSc Programme on Materials and Manufacturing Engineering
  - Micro Mechanical Systems Design and Manufacture (MSc course)
  - PhD Summer School on Multi-Material Micro Manufacture (since 2006)

Section of Manufacturing Engineering
Micro/Nano and Precision Manufacturing (MPP)

Si



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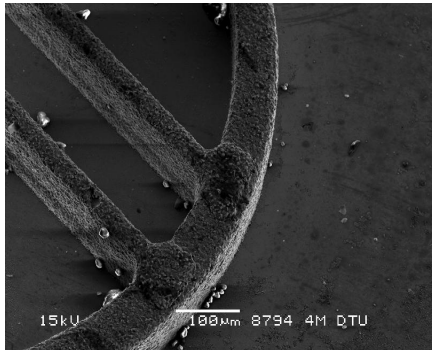

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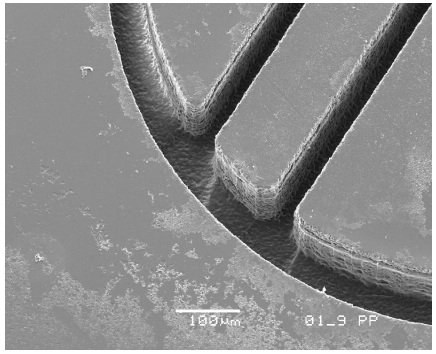
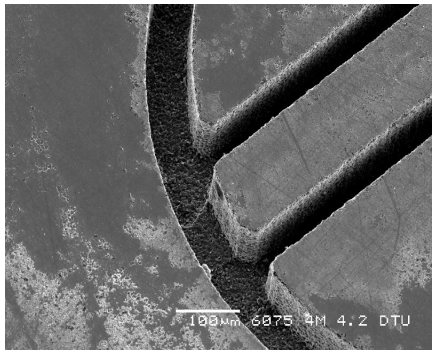


- **Group Leader** → Prof. Hans N. Hansen
- **Research Group** → Micro/Nano and Precision Manufacturing (MPP) (established on 2002)
- **Research projects focus** (European, national, industrial projects)
  - Mechanical, thermal and chemical manufacturing **PROCESSES** and their combinations
  - **MATERIALS** → metal, polymers and ceramics
  - Development, analysis and **SIMULATION** of processes, process machines, tooling systems
  - **MASS PRODUCTION** processes → µ-injection moulding and µ-forming
  - **GEOMETRIC METROLOGY** as the basis for decisions on control of modern constructions, manufacturing and function

Section of Manufacturing Engineering
Micro/Nano and Precision Manufacturing (MPP)

Si



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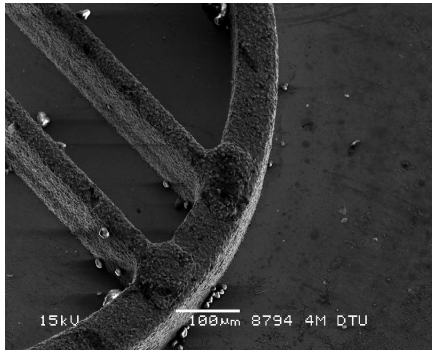

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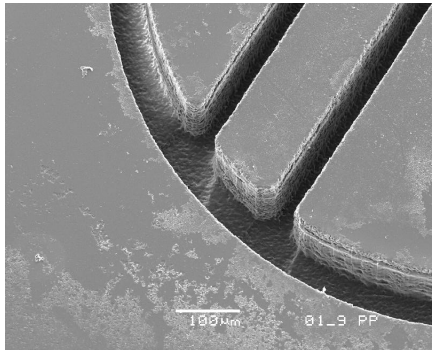
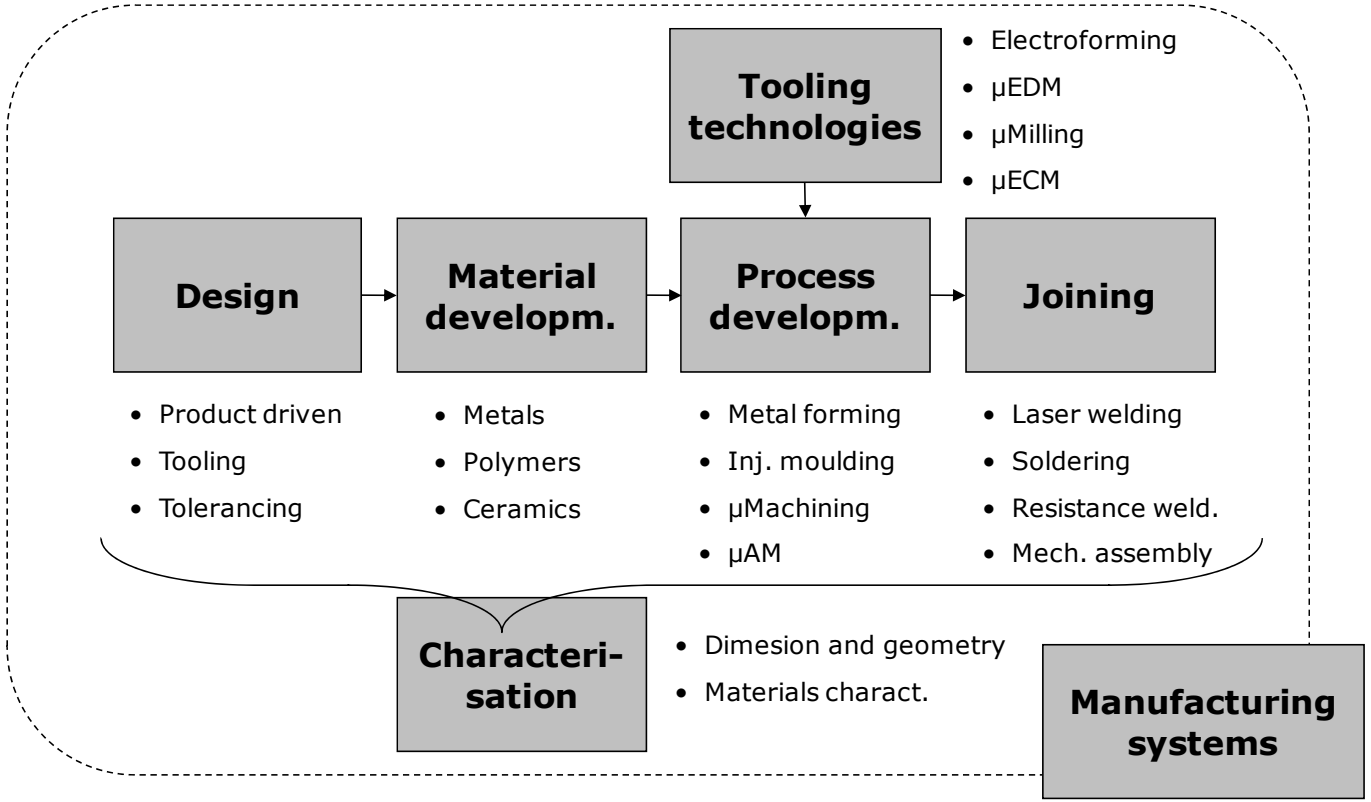
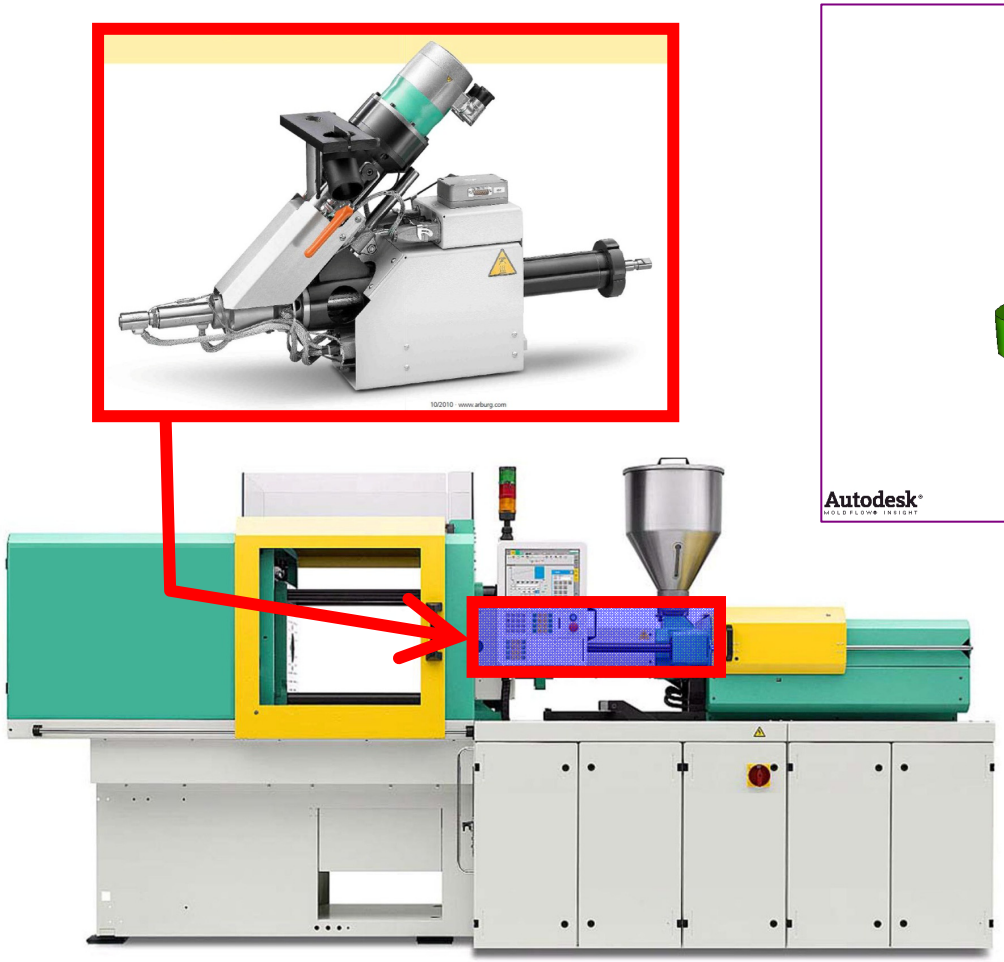
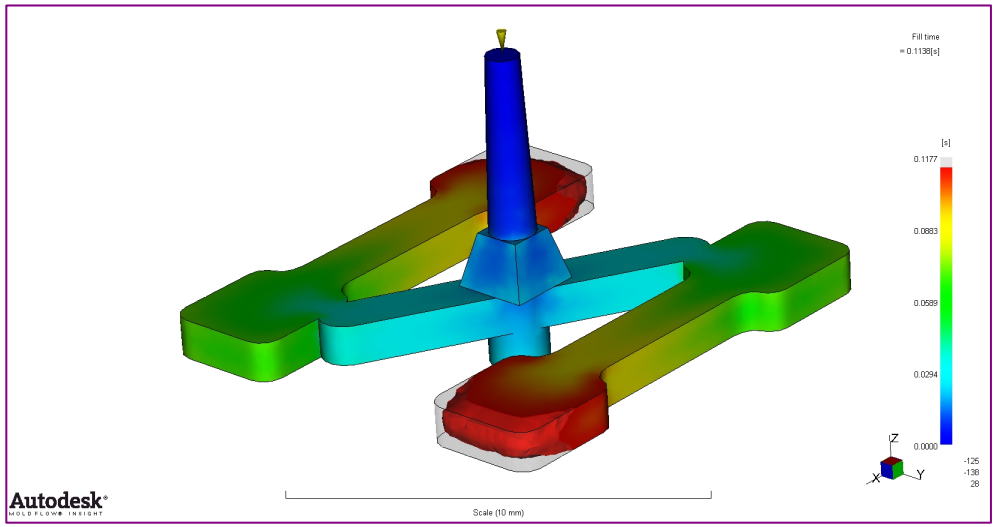




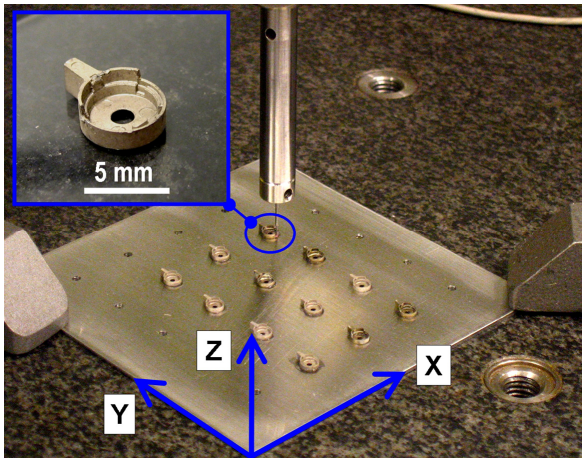
Injection Moulding (IM)
Micro Injection Moulding (µIM)
Injection Compression Moulding (ICM)

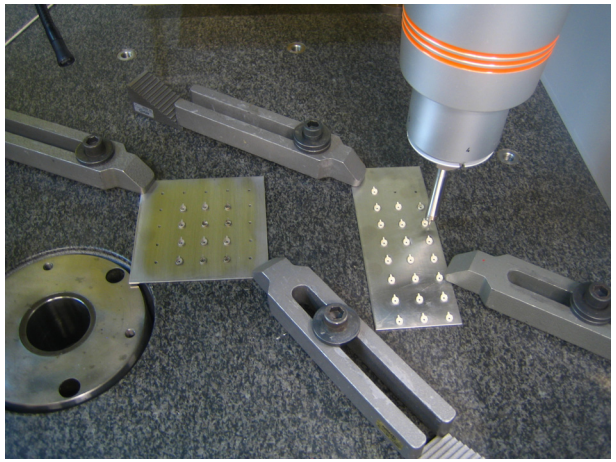




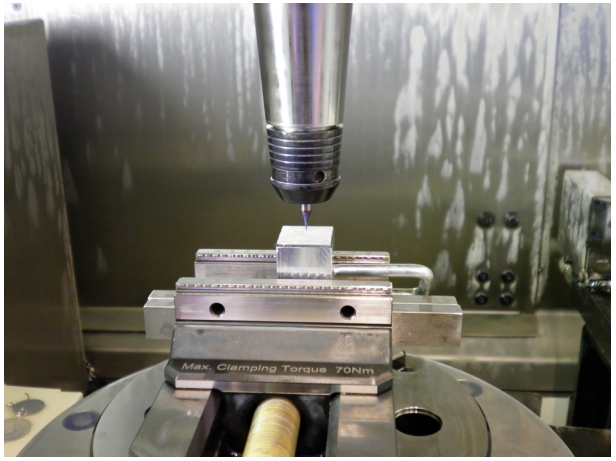
- Process development
- Process simulation
- Design & Tooling

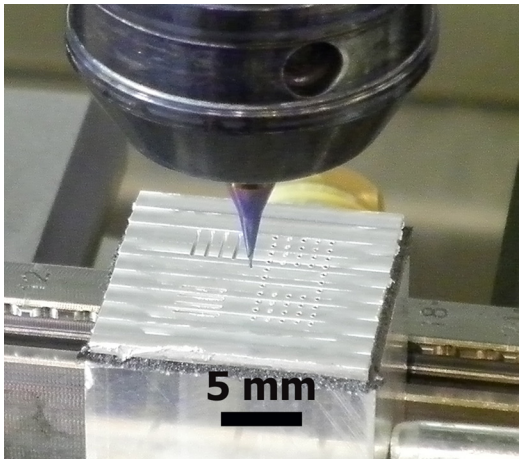
Section of Manufacturing Engineering
Laboratory of Geometrical Metrology

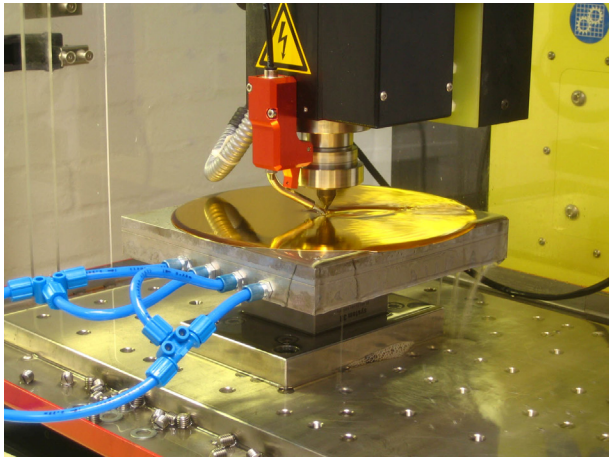


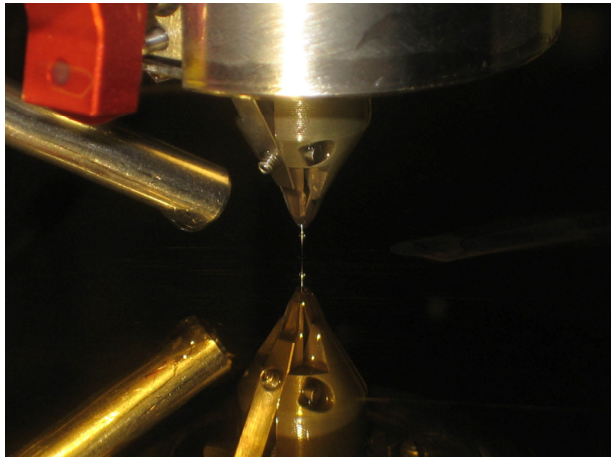


Precision & Micro Machining
Micro milling / Micro electrical discharge machining



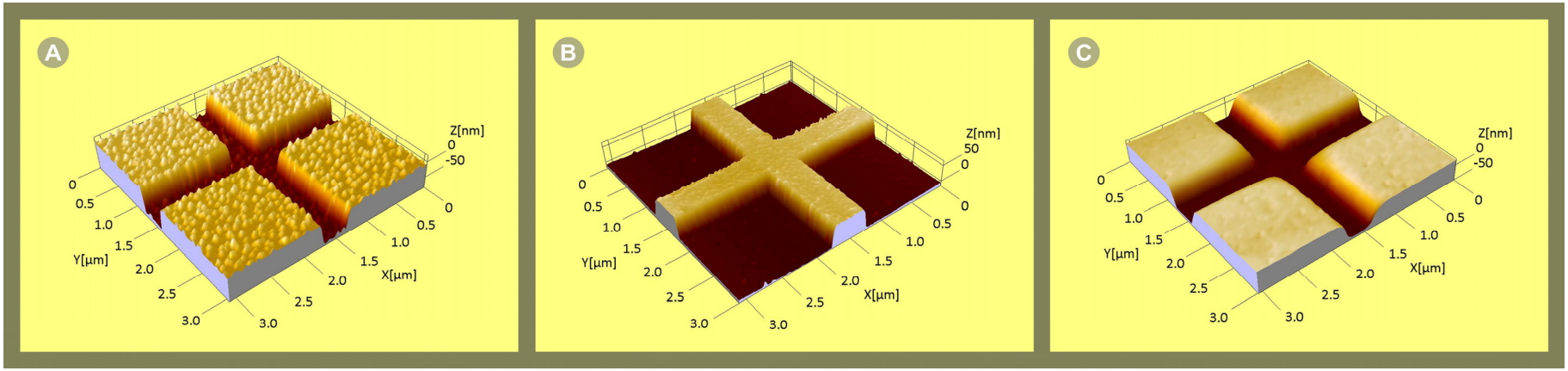






Research Projects (National / European) Micro/Nano/Multimaterial Manufacturing

- POLYMETAL DK (2005-2008) Metallization of polymers for micro manufacturing
- MASMICRO EU FP6 (2004-2008) Micro-assembly techniques for micro products
- 4M EU FP6 (2004-2008) Multi-Material Micro Manufacture
- NANOCMM EU FP6 (2006-2012) Flexible Coordinate Metrology for Micro and Nano Components Production
- COTECH EU FP7 (2008-2012) Converging Technologies for Micro Manufacture
- ***PolyNano DK (2011-2015) for Micro/Nano Fluidic Manufacturing Platform***
- ***Hi-Micro EU FP7 (2012-2015) High Precision Technology for Micro Manufacture***
- ***HINMICO EU FP7 (2013-2016) High Throughput Integrated Technologies for Multimaterial Functional Micro Components***



Thank you for your kind attention

DTU Mechanical Engineering
Department of Mechanical Engineering

Guido Tosello
Associate Professor, Ph.D.
Manufacturing Engineering

Technical University of Denmark
Produktionstorvet
Building 427S
DK-2800 Kgs. Lyngby

Tel. +45 4525 4763
Dir. +45 4525 4893
Fax +45 4593 4570

guto@mek.dtu.dk
www.mek.dtu.dk