FOP:s vårkonferens 2012, Sandviken/SWEDEN

High-Resolution X-Ray CT for 3D Failure Analysis and Metrology

Dr. André Egbert
Area Sales Manager
GE phoenix|x-ray, Wunstorf/D

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Outline

- GE phoenix|x-ray product line
- Principles of high-resolution X-ray CT
- CT for material science and failure analysis
- CT for 3D dimensional measurements
- Recent advances of high-resolution CT

GE Measurement & Control Solutions

Radiography Product Line

phoenix|x-ray

GE imagination at work

GE: A company with global reach

- 125+ years
- >300,000+ employees
- 2009 $157B Rev
- In >100 countries

Measurement & Control Solutions (MCS)

7,000 employees
60 countries
2010 $2B Rev

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MCS Product Lines

Inspection Technologies

- Radiography, Film, CT, CR/DR,
- Ultrasonic, Eddy current
- Remote Visual
- Software

Measurement Solutions

- Flow
- Gas and Moisture
- Pressure

Advanced Sensors

- Temperature
- Pressure (MEMS)
- Infrared
- Validation

Bently Nevada

- Monitors
- Field devices
- Tech support
- System 1® software
- Machinery diagnostics

Control Solutions

- Retrofits and parts
- EX2100
- Mark IV, V, VI, VIe
- OC 4000 DCS
- Software upgrades

Reuter Stokes

- Nuclear instrumentation
- Flame detectors
- He-3 detectors
- Scintillations sensors
- Mechanical assemblies

The MCS Radiography Product Range

Film & Equipment

- Complete range of Agfa X-ray films
- State-of-the-art processing equipment
- Film Scanning

Digital Radiography

- Computed Radiography
- Reusable Phosphor plates
- Digital Detector Arrays
- Image processing and storage software

X-ray Sources

- Portable and mobile X-ray systems
- Stationary systems
- Micro- and nanofocus tubes and generators

2D Systems

- Stationary manual and automated digital X-ray inspection systems
- Fully automated defect recognition software

3D CT

- 3D industrial failure analysis with CT
- 3D CT systems for materi-als research, bio- and geosciences

CT

3D Metrology

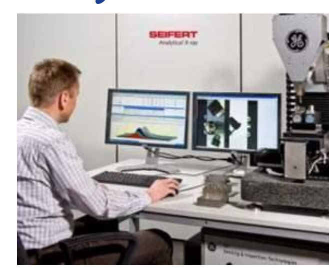
- Reproducible 3D coordinate measurement with X-ray CT
- Fully automated CT data acquisition and volume processing

Electronics Inspection

- 2D micro- and nano-focus X-ray
- Software for high resolu-tion electronics inspection
- CAD-based programming

phoenix|x-ray

X-ray Diffraction



- Quantitative and qualitative phase analysis, structure and tension measurement
- Single crystal materials orientation analysis

Product line phoenix|x-ray

- A leading manufacturer of high-resolution 2D X-ray inspection and 3D computed tomography systems for non-destructive testing and 3D metrology

- Founded 1999 in Wunstorf / Germany

- 2007 acquired by GE Sensing & Inspection Technologies

- More than 1800 installations

- Development and production in Germany

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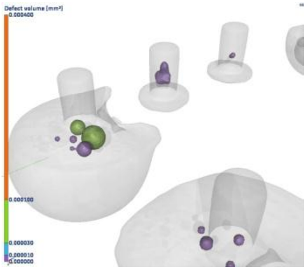
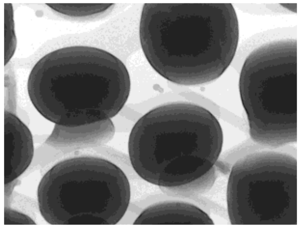
X-ray Electronics Inspection

- Leading edge 180 kV micro- and nanofocus X-ray tube technology
- Live imaging with GE´s unique DXR digital detector technology
- Efficient CAD programming with minimized setup time
- Easy and fully automated X-ray inspection of PCB assemblies
- Live 3D CAD data and inspection result overlay in the X-ray live image
- Extremely high defect coverage with high magnification and repeatability





- phoenix inspector
- phoenix x|aminer
- phoenix microme|x
- phoenix nanome|x

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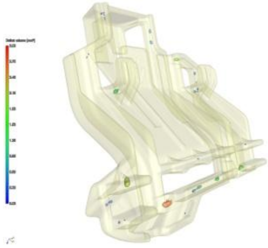
High resolution Computed Tomography

- Non destructive 3D defect analysis for quality assurance and production control
  - Precise quantitative analysis of position, size and frequency of defects
  - Multi-positional 2D cross-section planes or 3D volume view

- Wide range of nanoCT® materials sciences applications
  - Leading 180 kV high power nanofocus X-ray technology
  - Closest to synchrotron CT in many application fields

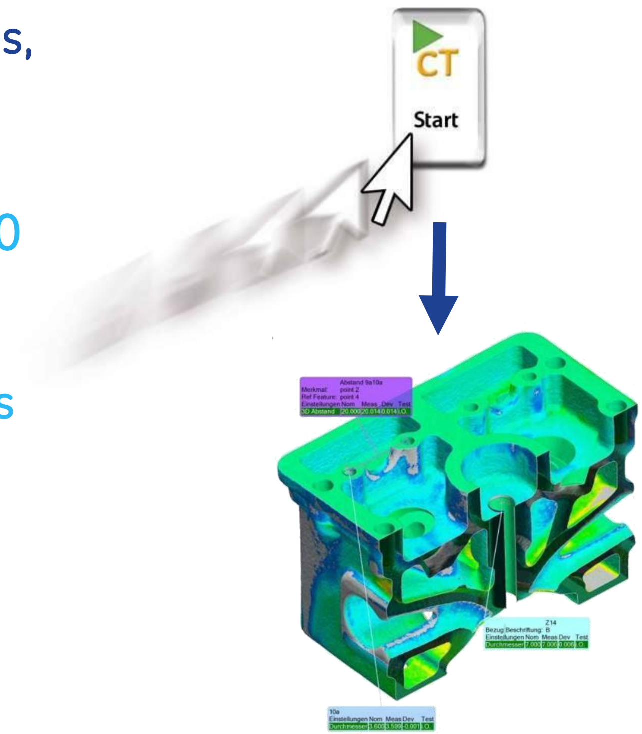


- phoenix v|tome|x s / m / L
- phoenix nanotom s / m

3D Metrology with CT

- CT precision comparable to tactile Coordinate Measurement Machines (CMMs)
  - Reverse Engineering
  - Nominal/actual comparison
  - Dimensional measurement
    (e.g. internal wall thickness, distances, holes, radiuses, angles etc.)

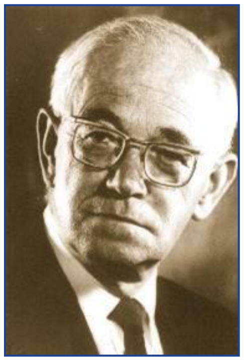
- Click & measure|CT with phoenix datos 2.0
  - Automated execution of CT scan, reconstruction, analysis process and generation of first article inspection reports within one hour



GE Measurement & Control Solutions

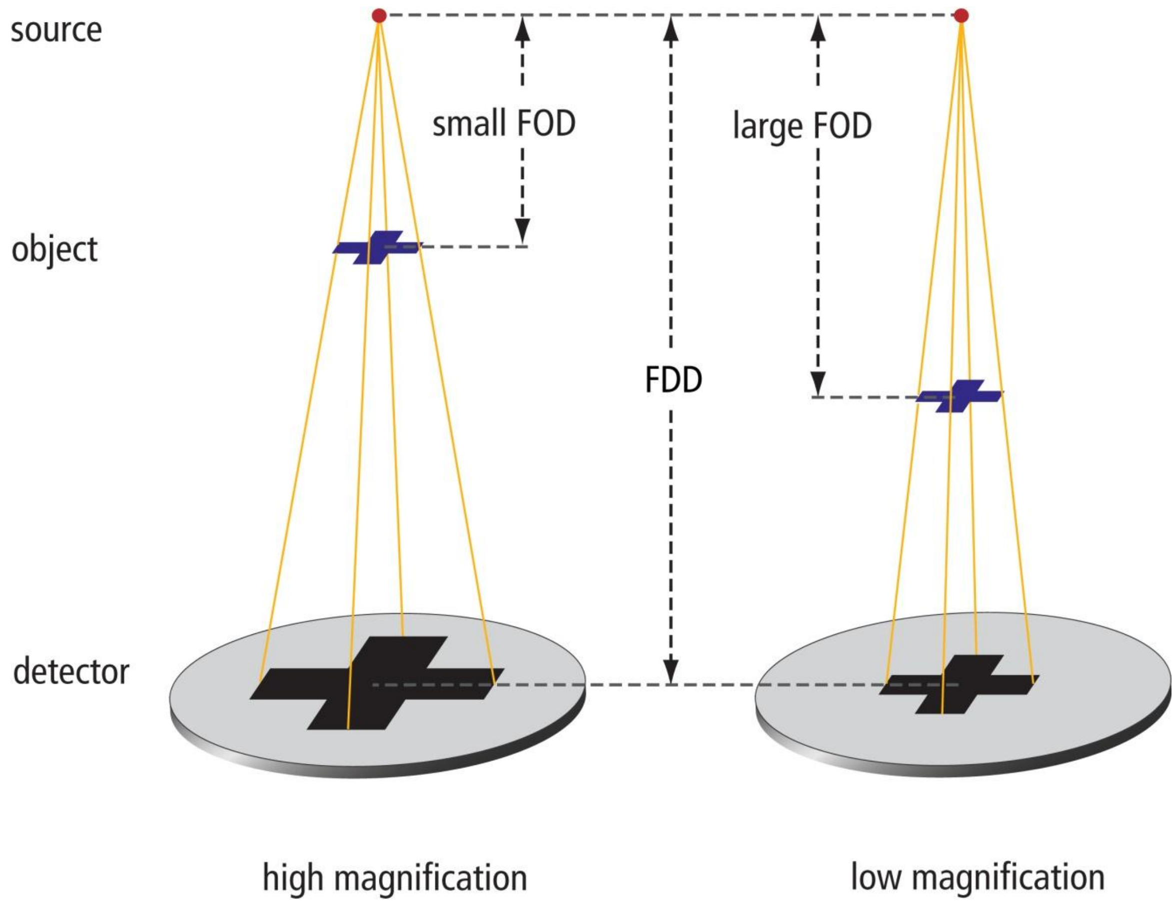
Principles of high-resolution X-ray computed tomography

Principle of operation



V.E. Cosslett
W.C. Nixon
Cambridge 1951

"X-ray Shadow Microscope" Nature 10 (1951) S.24 ff.



The X-ray shadow microscope

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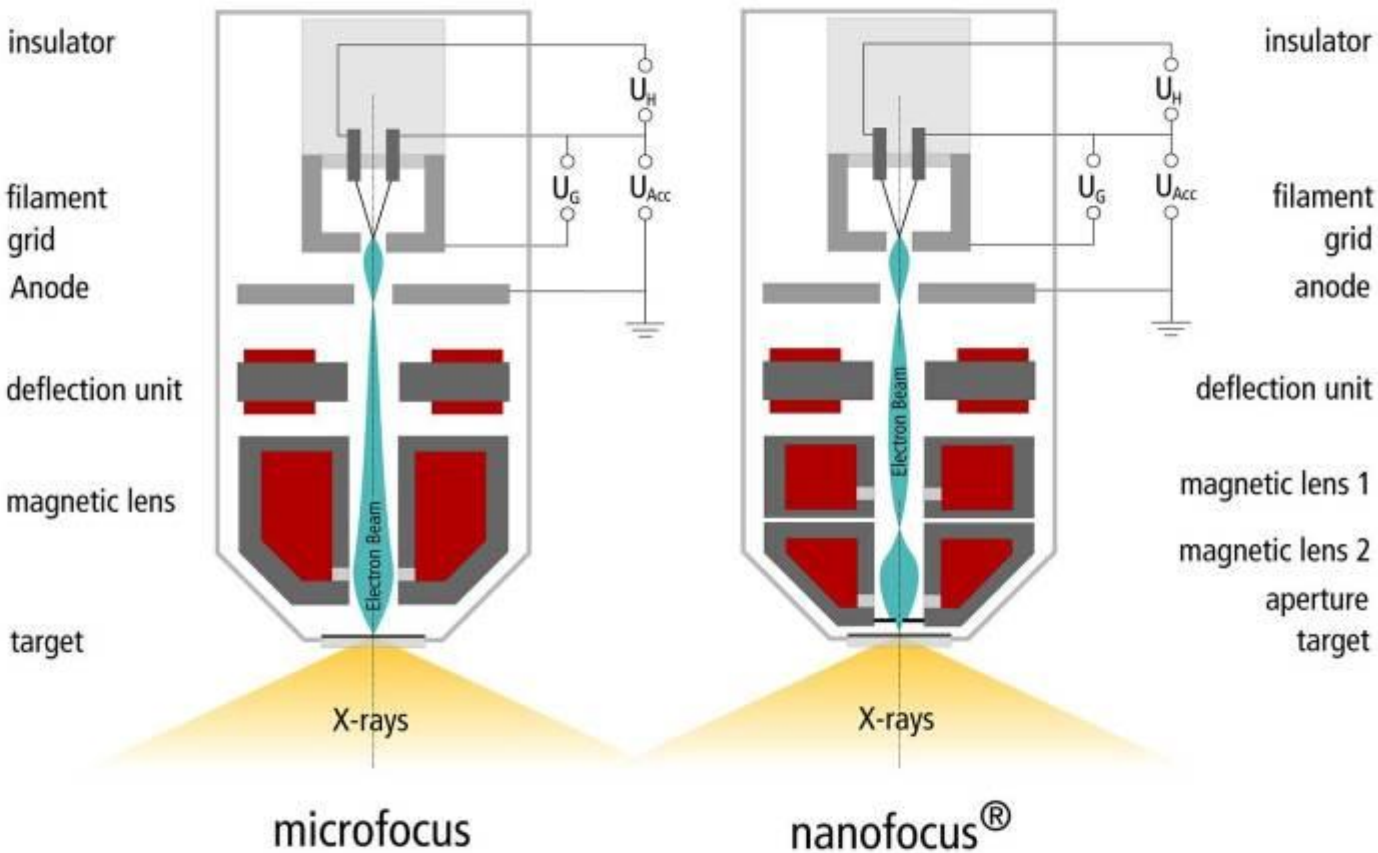
X-ray tubes
Microfocus vs. nanofocus®



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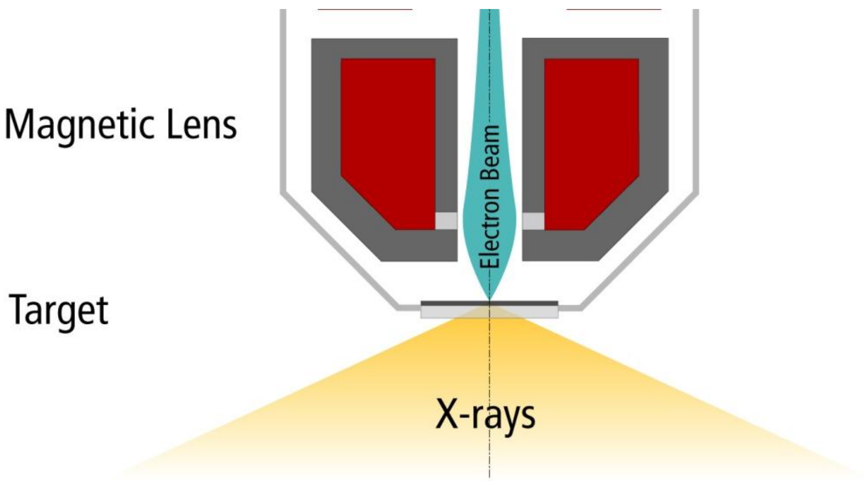
X-ray tubes

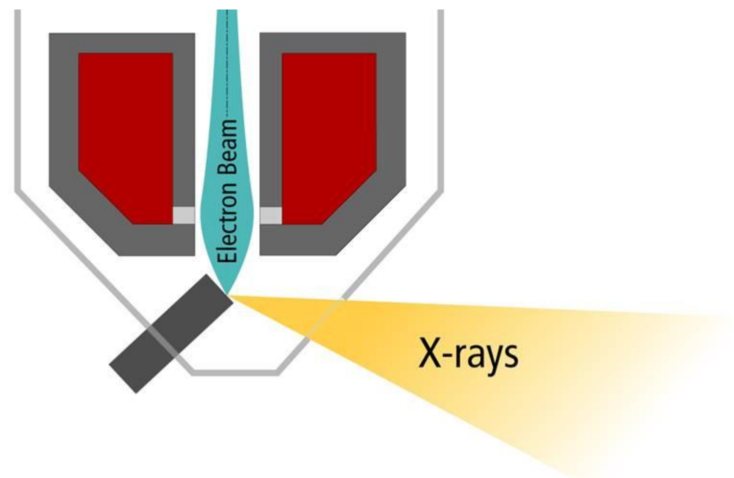
Directional - Transmission

Transmission Target



higher magnification

Directional Target

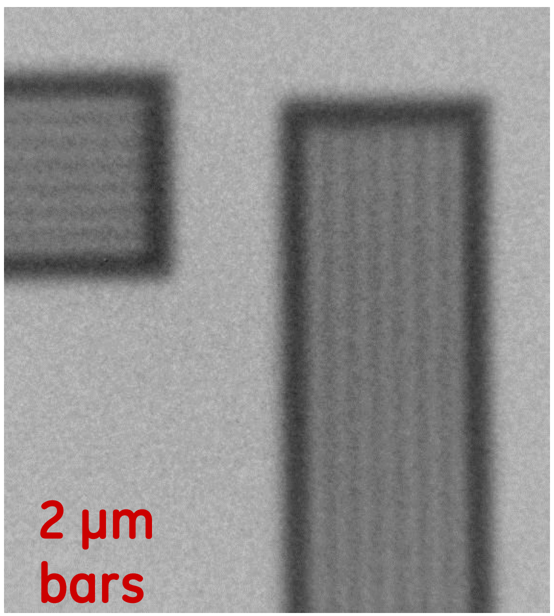


higher power

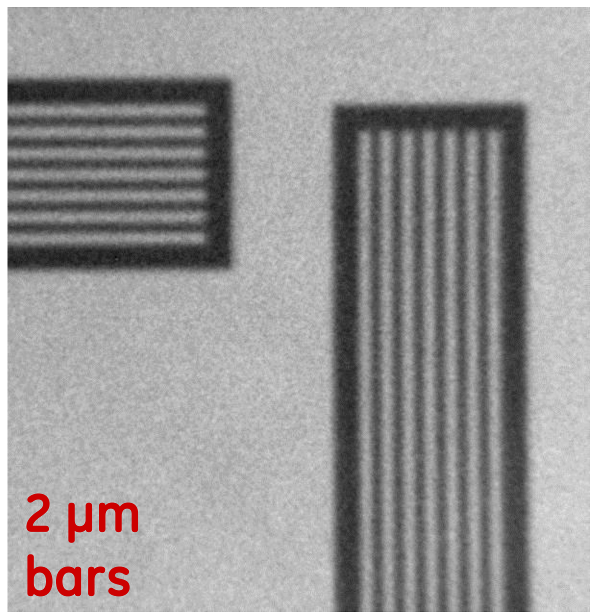
Resolution

Focal Spot size influence:

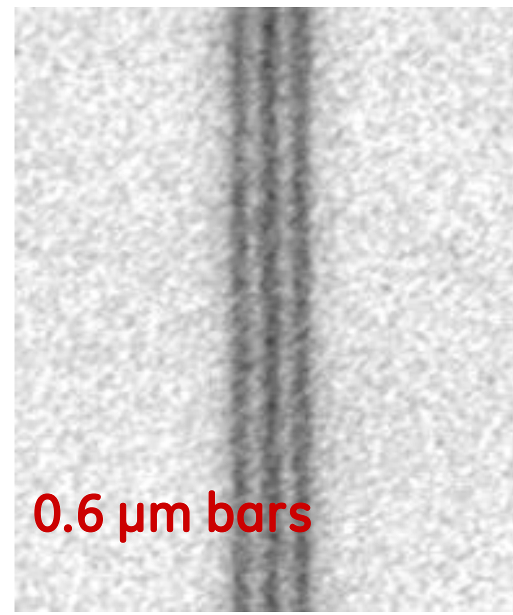
Ø 2.5 µm



Ø 1.5 µm



Ø 0.8 µm



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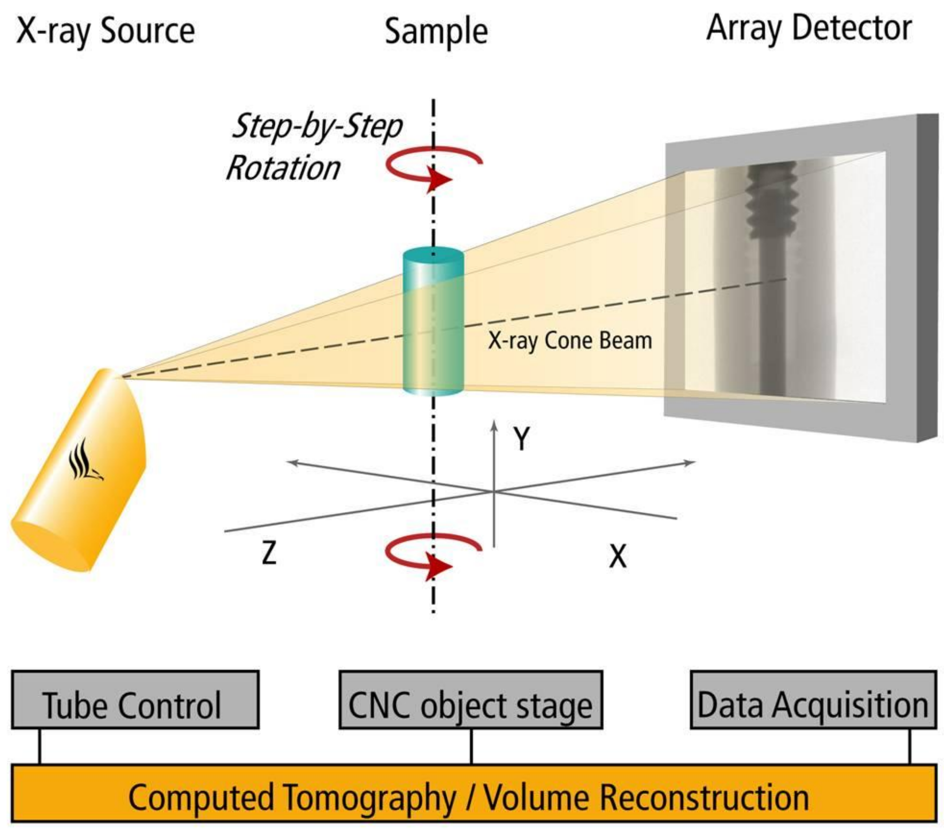
Principle of computed tomography

Acquisition: cone beam

of 2D projections under step-by-step rotation

steps< 1°



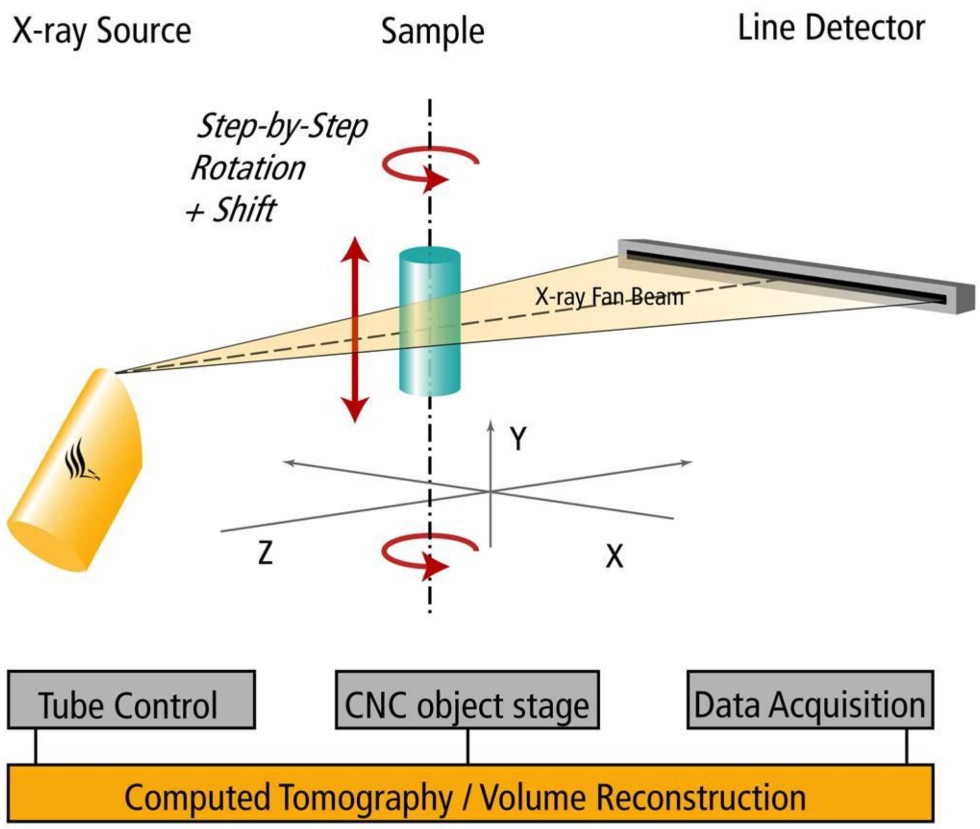
imagination at work

Principle of computed tomography

Acquisition: fan beam

of line projections
under step-by-step
Rotation and shift

steps< 1°



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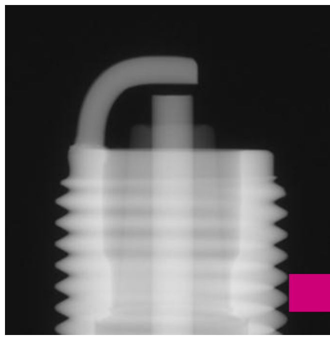
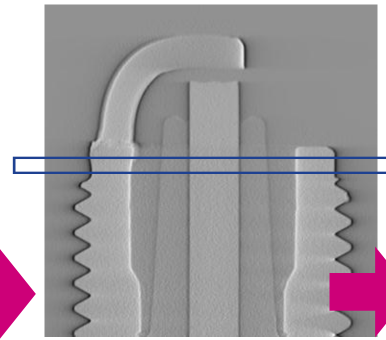
Principle of CT: Reconstruction Method

Example: spark plug

projection

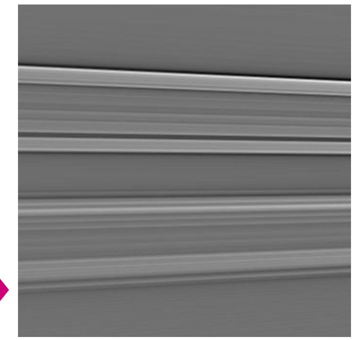


inversion



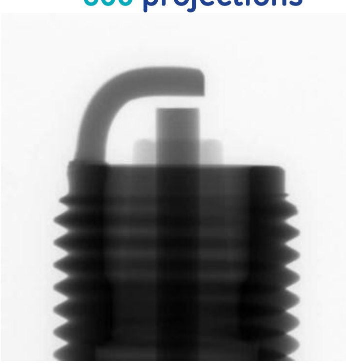
log + filter

line profile

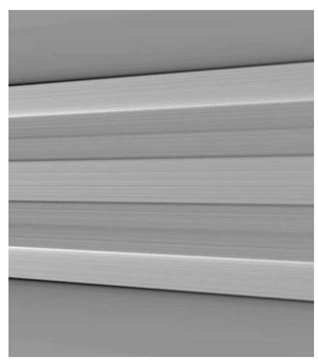


back-projection

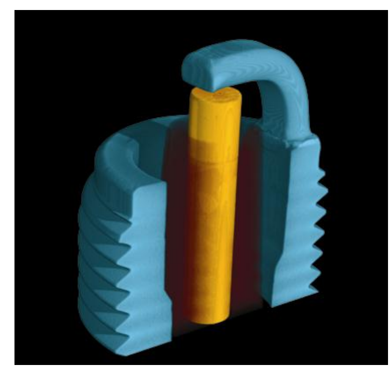
Acquisition of 600 projections



600 back projections



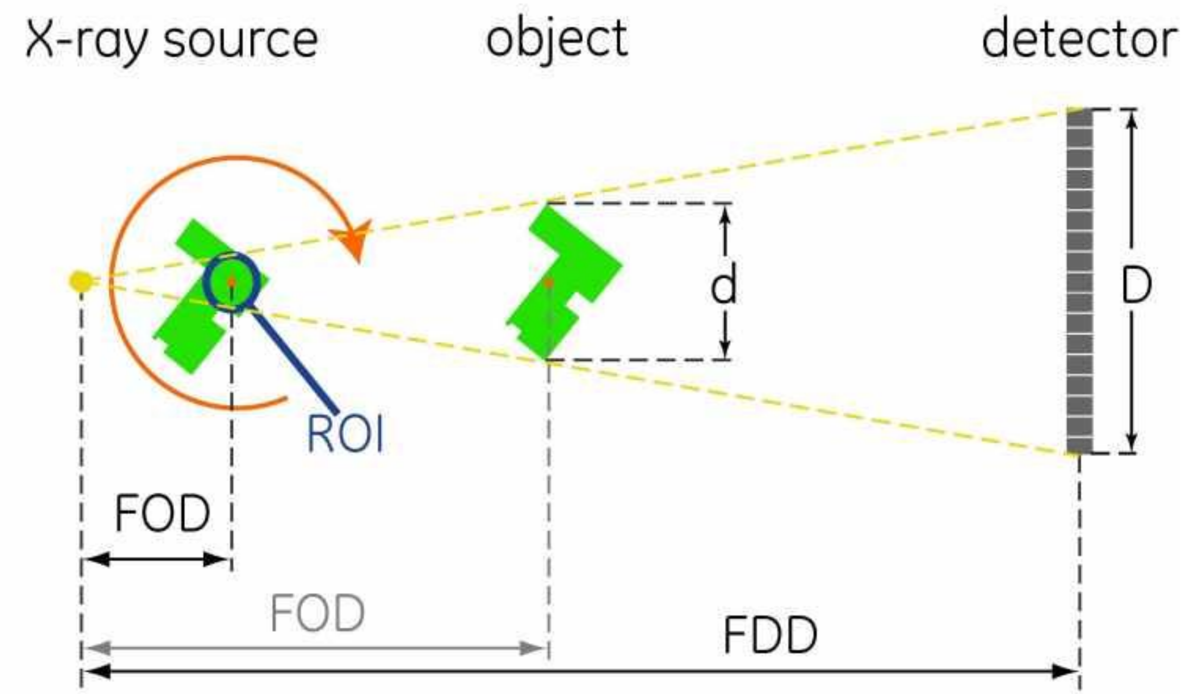
3D visualisation



Principle of Operation: CT resolution

Three contributions from apparatus:

- voxel size V=P/M
- focal spot size F
- mechanics

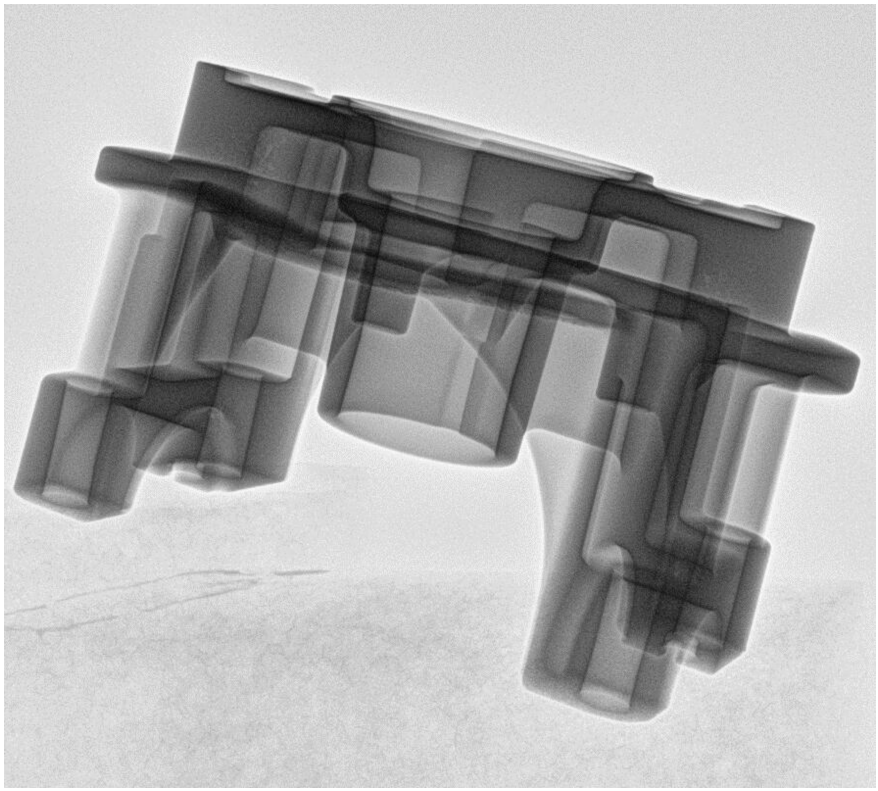


M=FDD/FOD

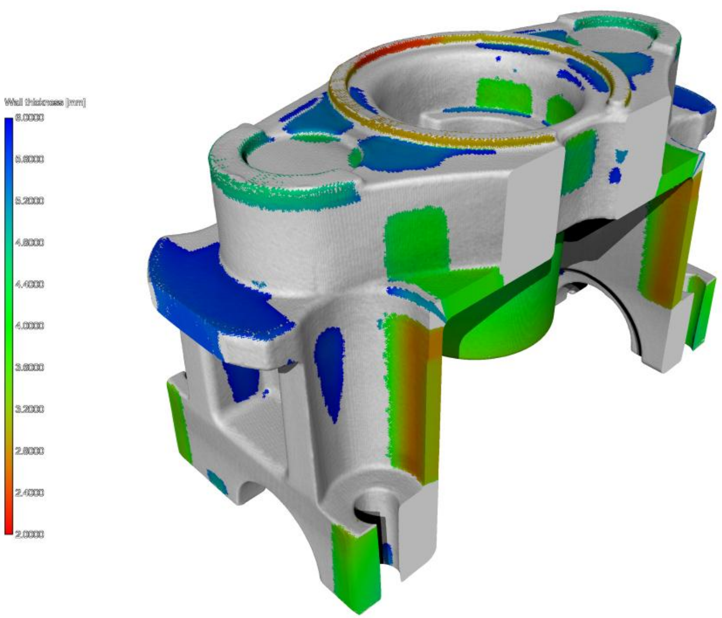
The focal spot size F is the ultimate limit of resolution.

Benefits of Computed Tomography Example: Al Casting

Microfocus 2D X-ray image



Microfocus 3D CT dataset



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X-ray CT systems

nanome|x CT

nanotom m

v|tome|x s

nanotom s

v|tome|x m

v|tome|x L 300

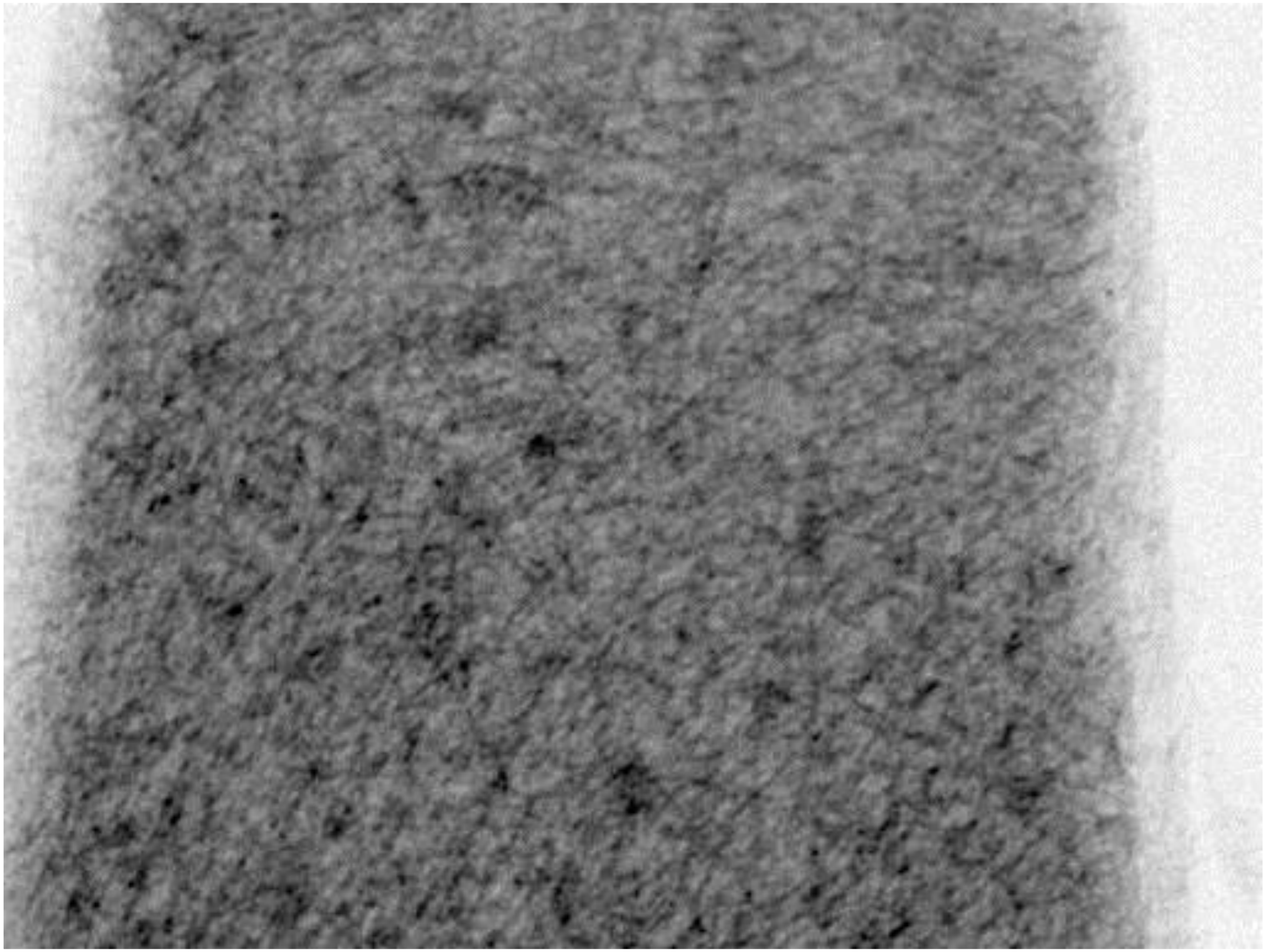
v|tome|x L 450

GE Measurement & Control Solutions

CT for material science and failure analysis

Glas fibre reinforced material

2D X-ray image



- 2D: Only the average density is visible
- 2D: Voids would be visible

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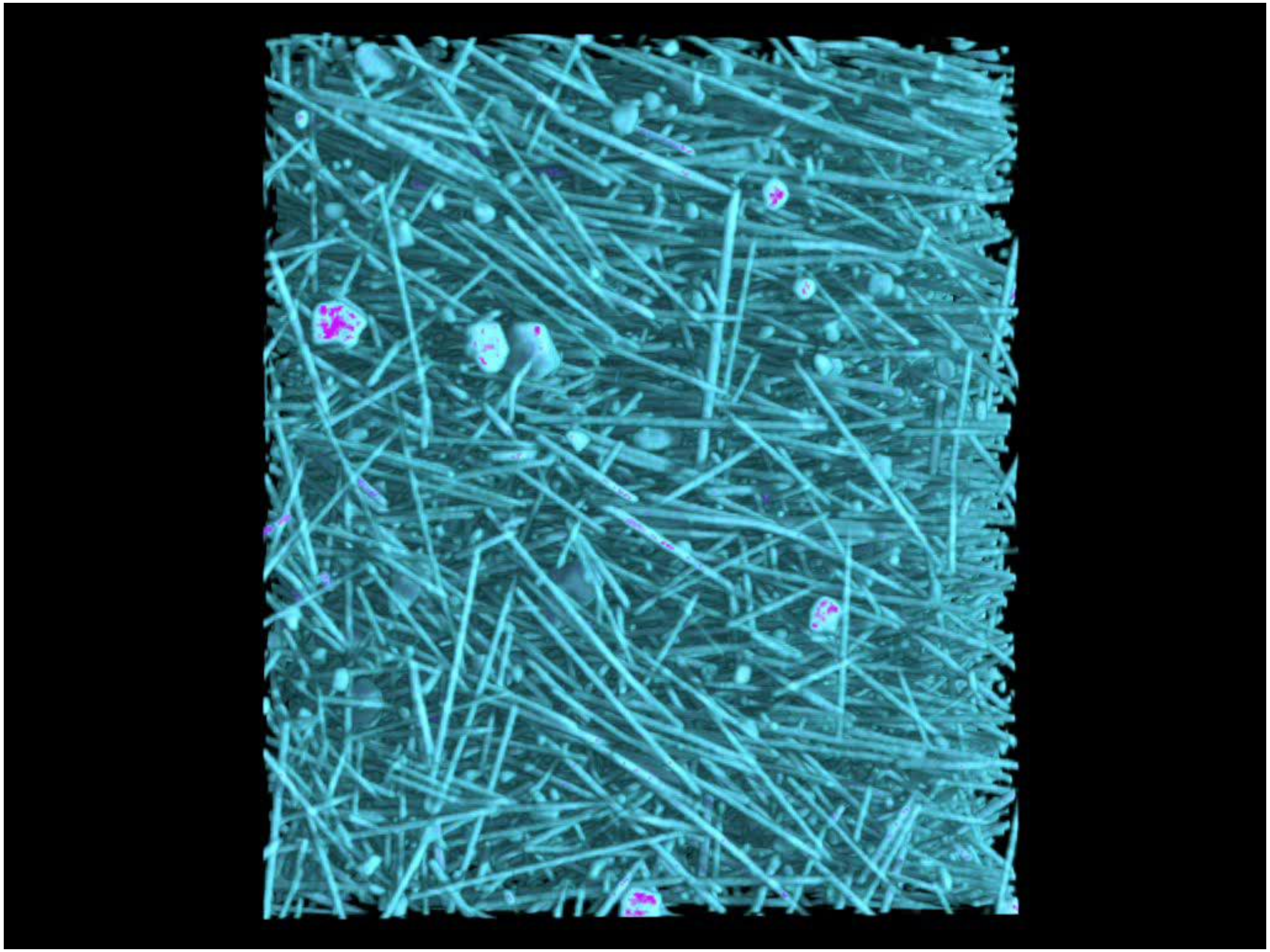
Glass fibres with particles

nanoCT®



- Orientation and distribution of the 10 µm thin fibers
- Accumulations of the mineral filling material

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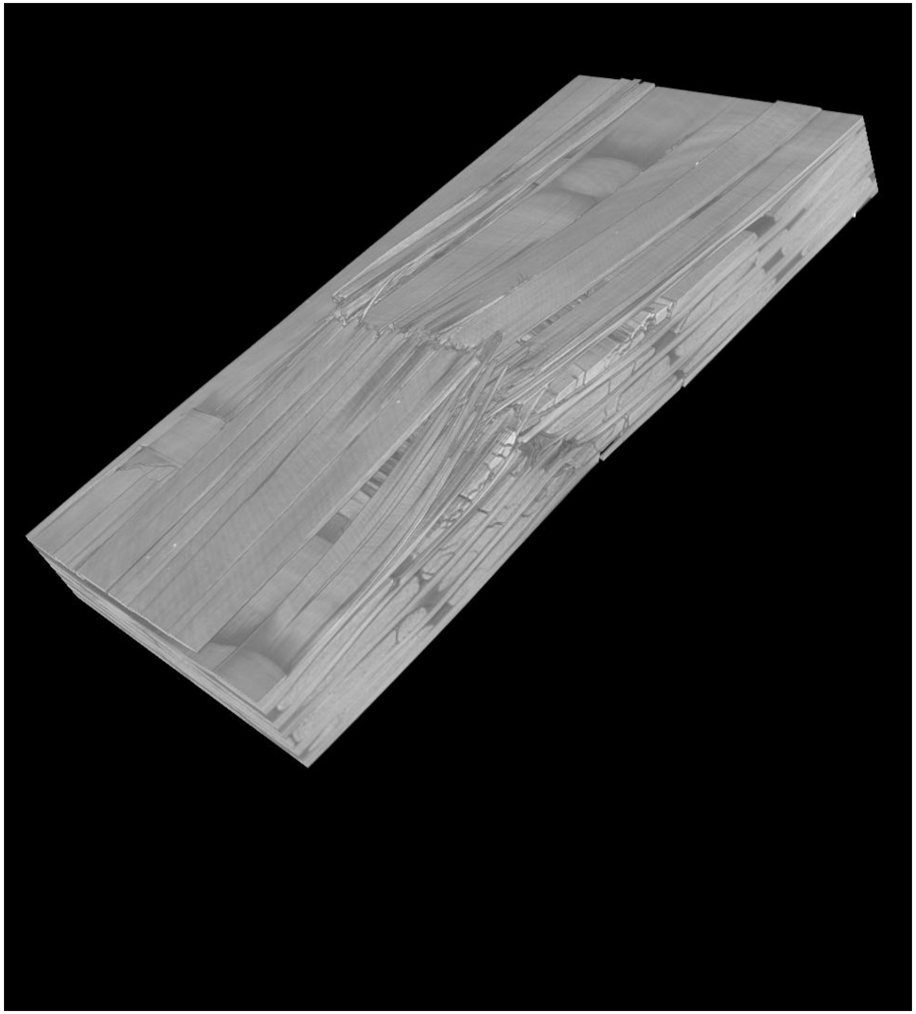
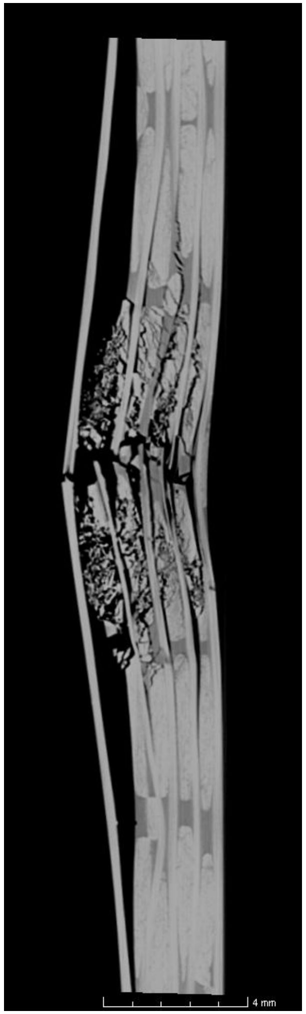
Carbon fibre composites

CT results

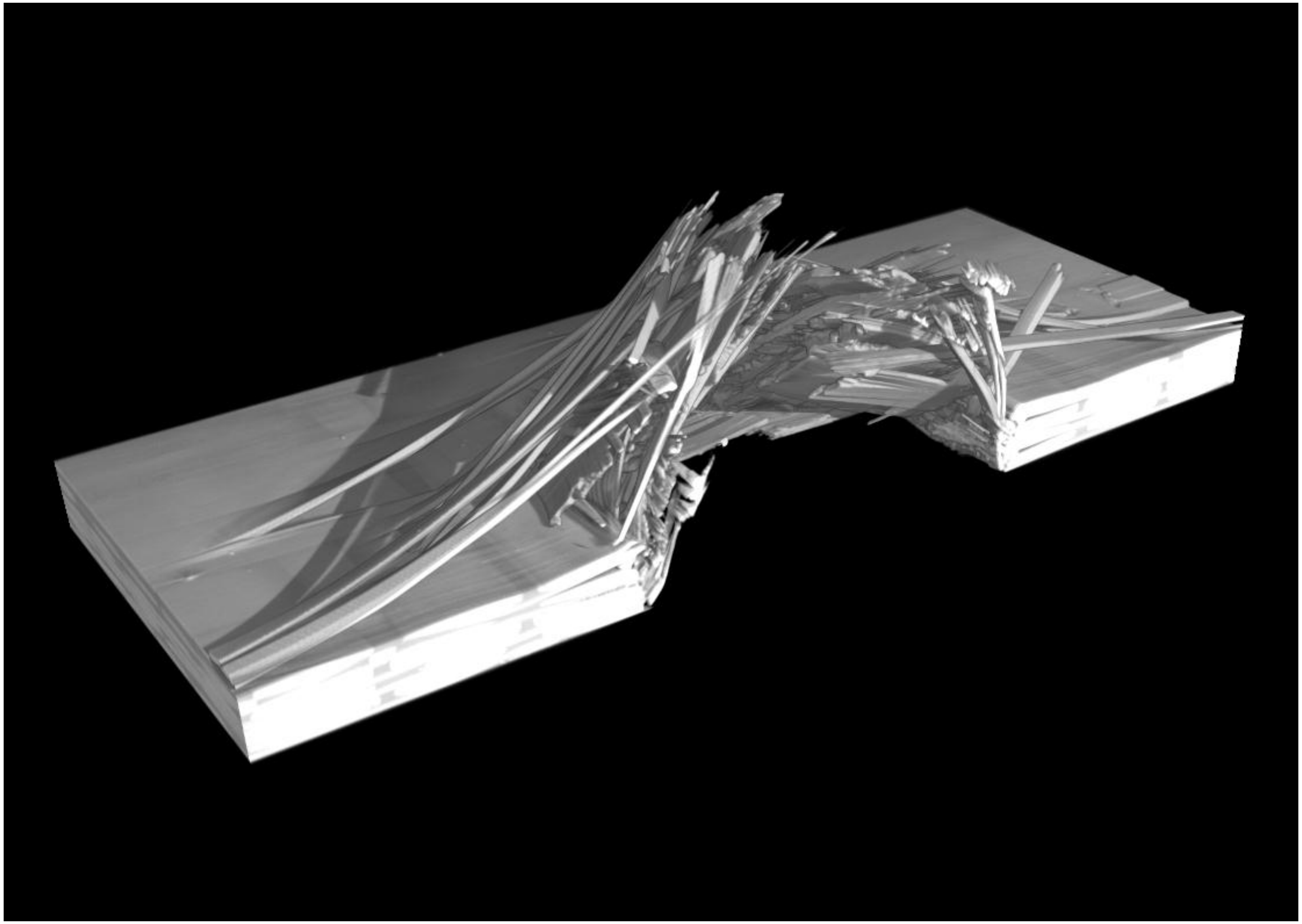




- **Impacted carbon fibre composite plates**

Carbon fibre composites

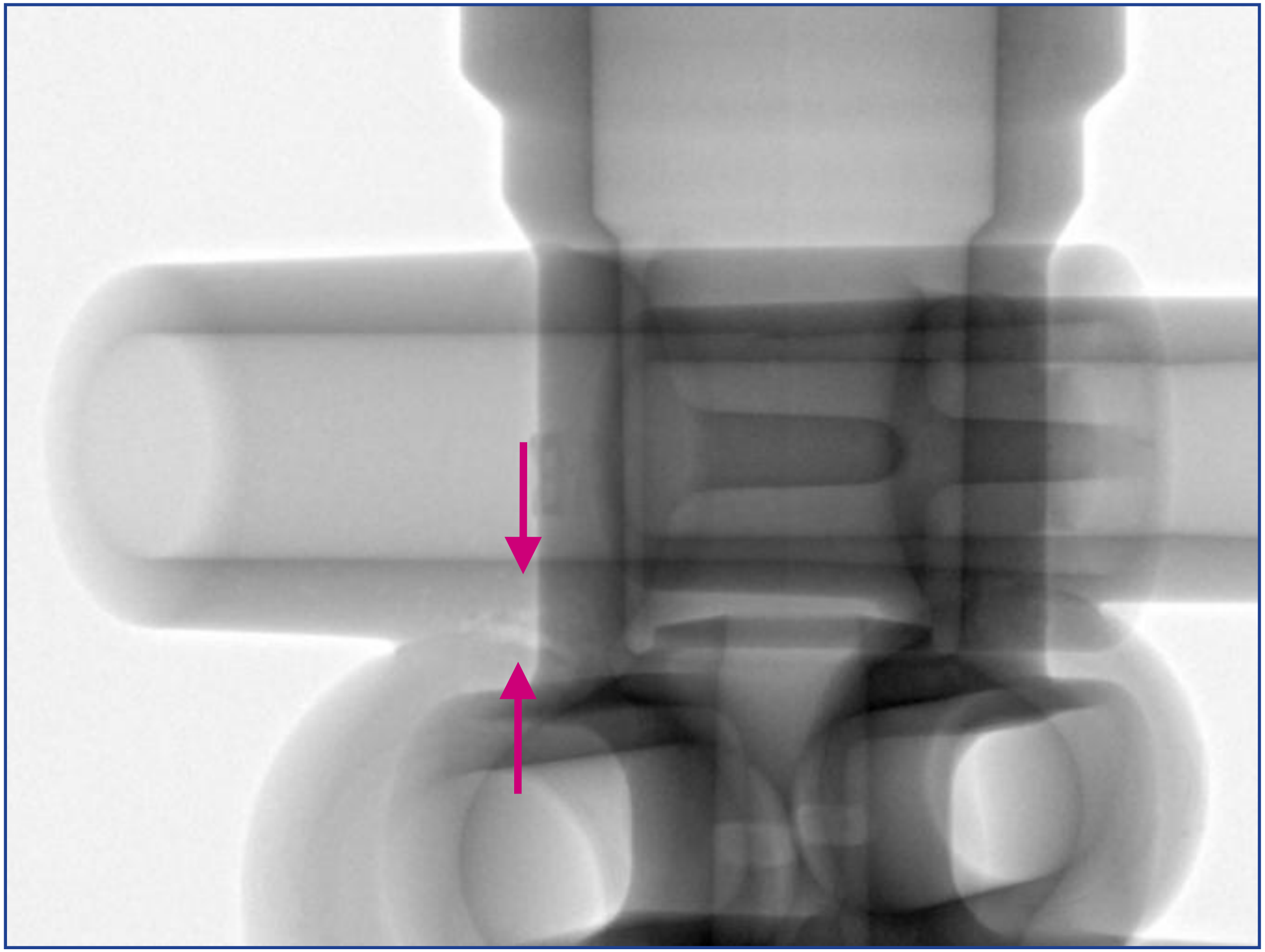
CT results



- **Impacted carbon fibre composite plates**

Aluminum casting

2D X-ray image



- **Detection of imperfections, such as shrinkage, cracks, inclusions**

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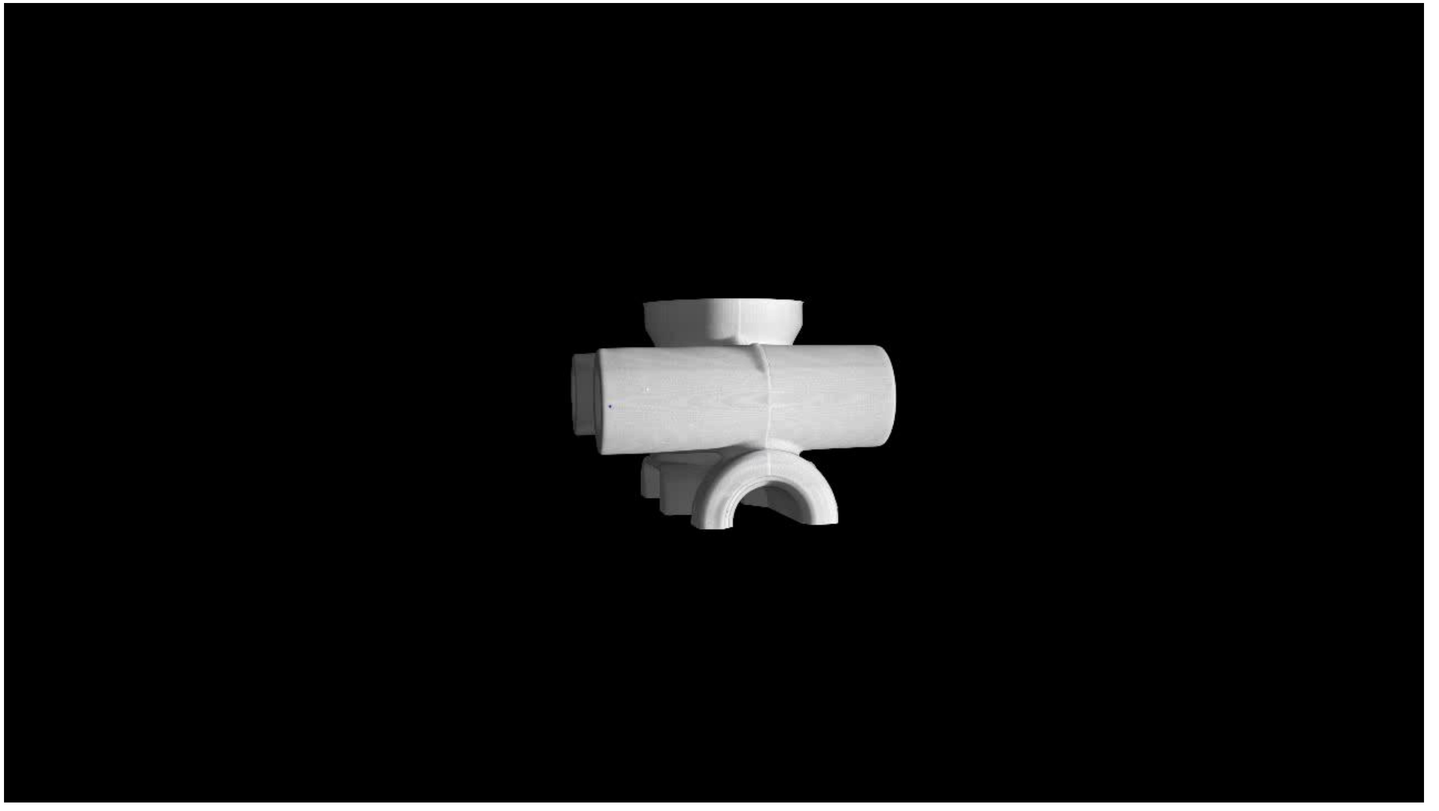
Aluminum casting

CT volume



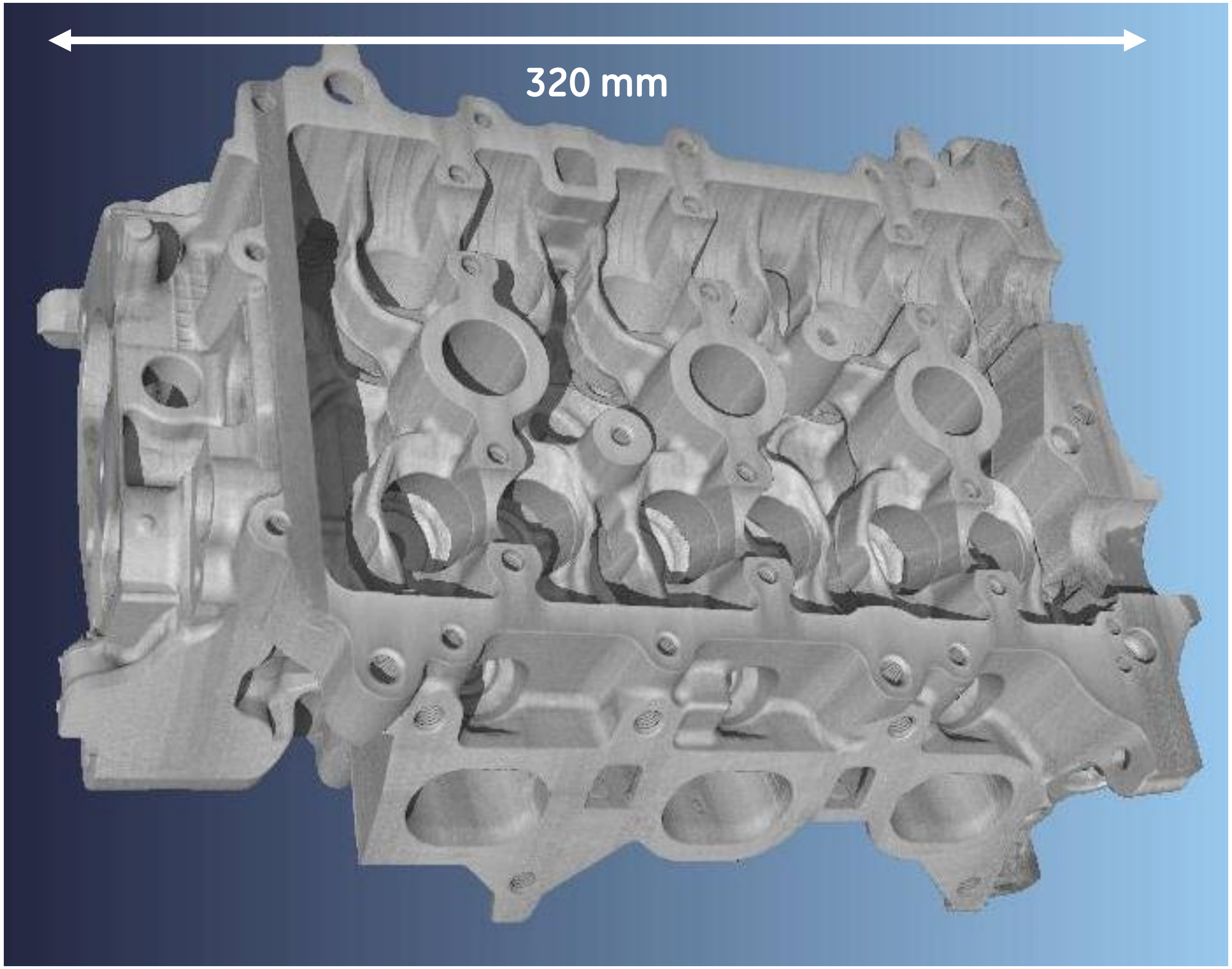
- Classification of void size in colours

Cylinder head

3 Cylinder-motor

450 kV Multiline Scan

0.14 mm voxel size (isotrop!)



Typical tasks

- Void detection, wall thickness analysis, metrology

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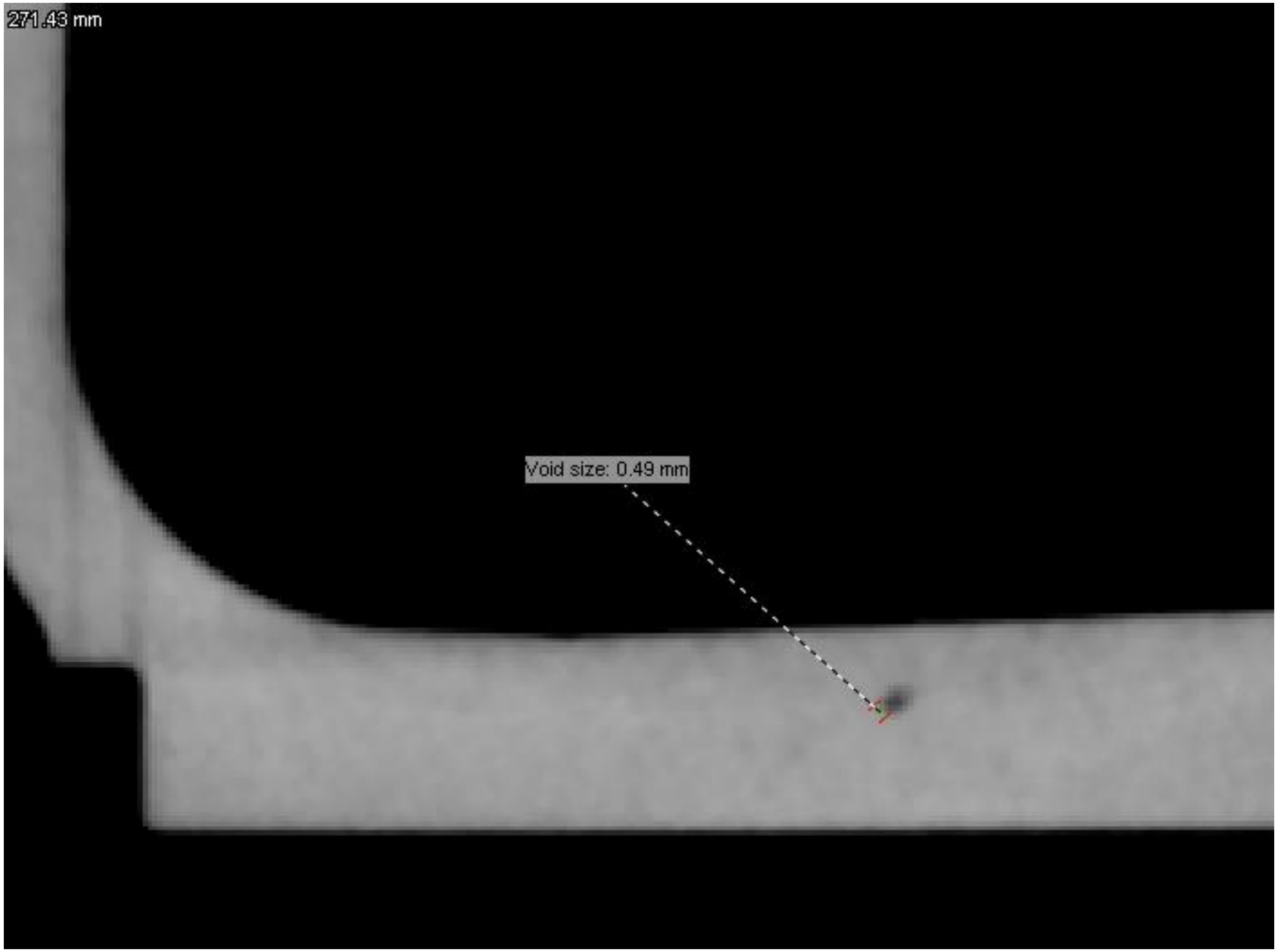
Cylinder head

3 Cylinder-motor

450 kV Multiline Scan

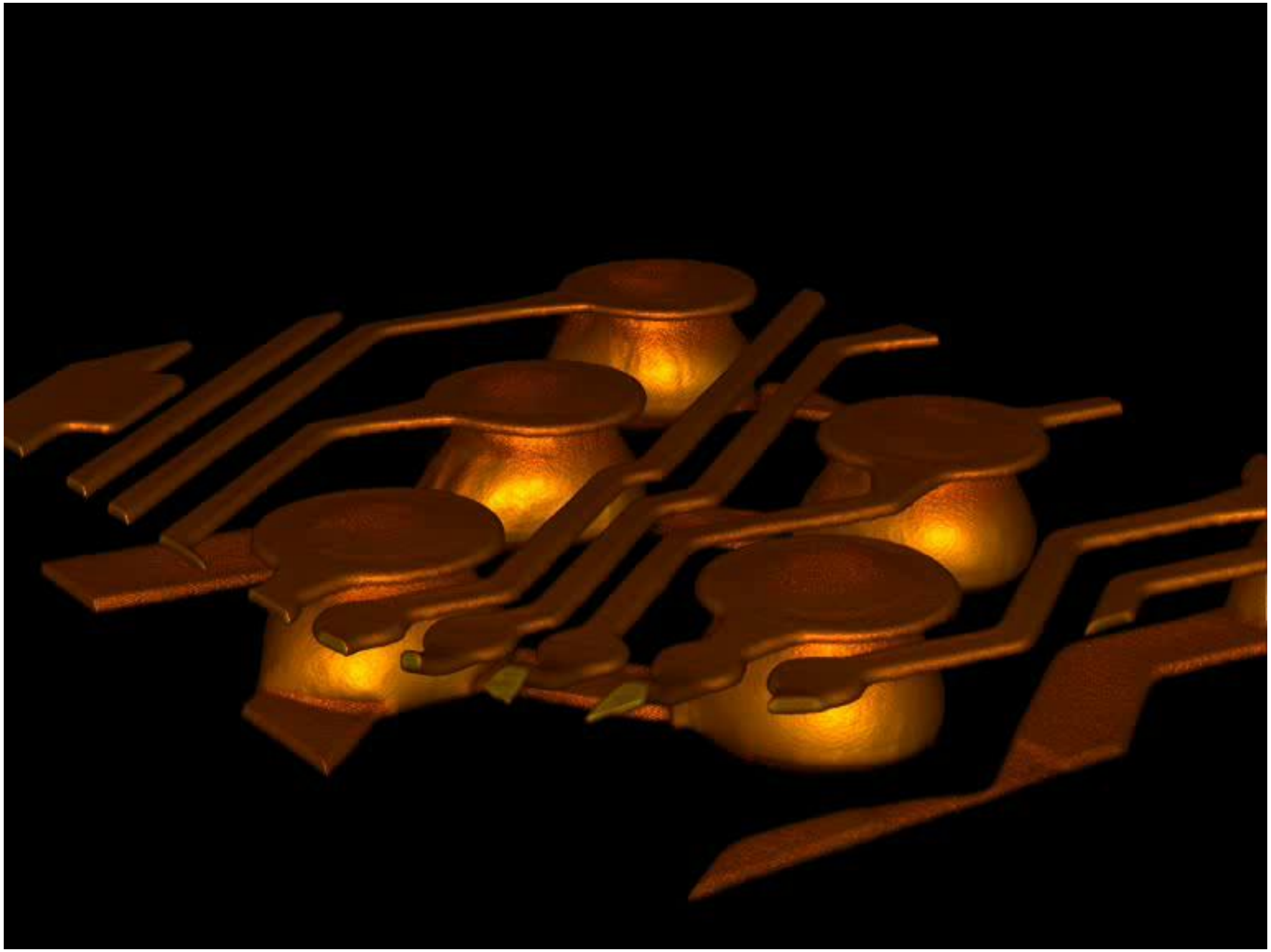
0.14 mm voxel size (isotrop!)



- Defect analysis (voids).

BGA/CSP solder joints

3D movie



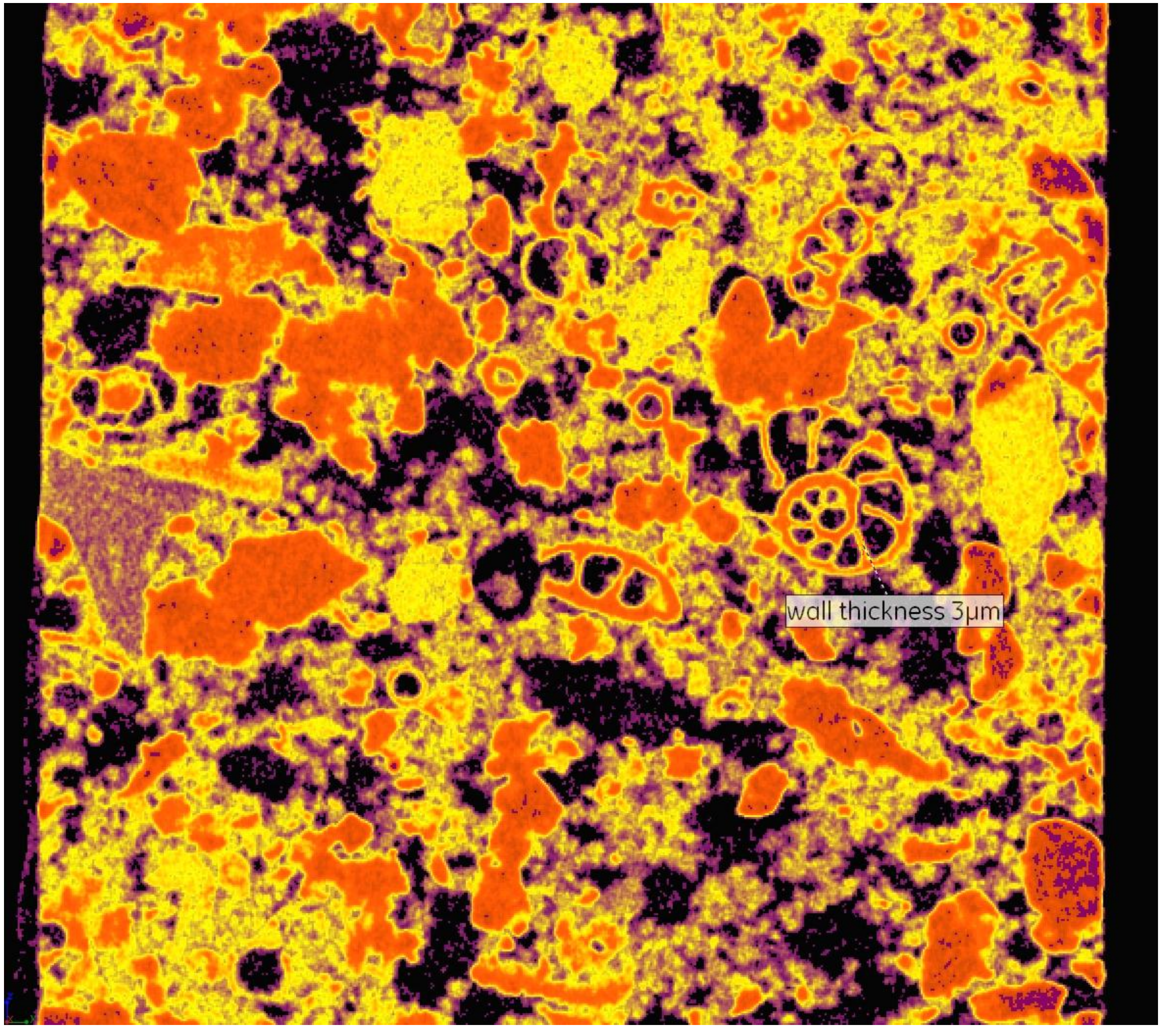
- 3D: wetting conditions and void positions are visible, lead phases are visible
- Solder joints with 400 µm diameter

imagination at work

Slice through the 3D volume of a shell limestone with microfossils (Ø 0.7 mm)

Courtesy of O. Rozenbaum, ISTO France

Vx = 1.2 µm



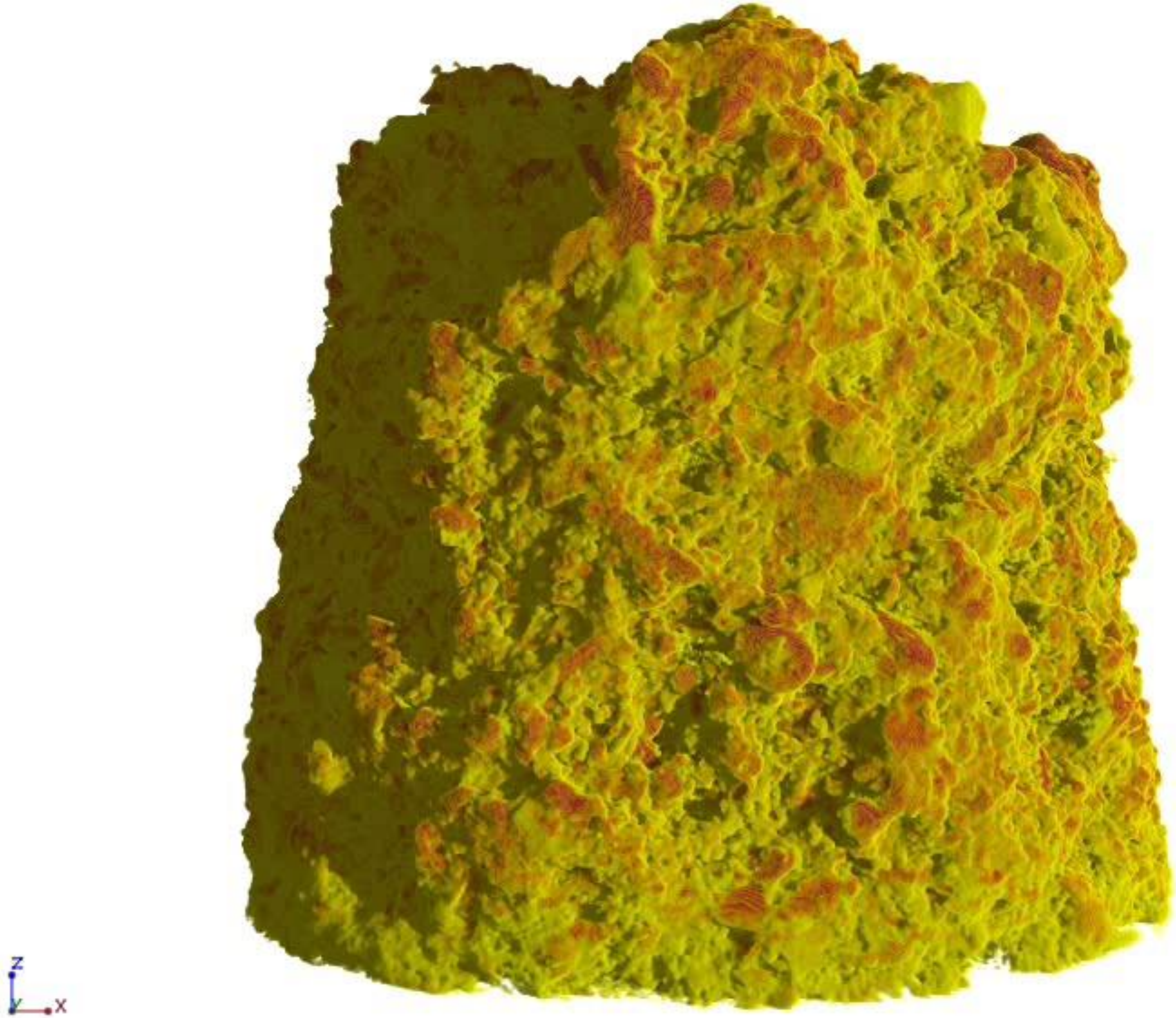
- Zoom into a tomographic slice to measure the wall thickness (~3µm) of a small ammonite

imagination at work

Virtual flight through the 3D volume of a shell limestone with microfossils (Ø 1.8 mm)

Courtesy of O. Rozenbaum, ISTO France

Vx = 1.25 µm



- Movie: Flying around the sample, slicing and fading out

imagination at work

Hoverfly

35 kV
Molybdenum
target

- 3 µm voxelsize
- even eye facet structures are clearly visible

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3D Metrology with CT

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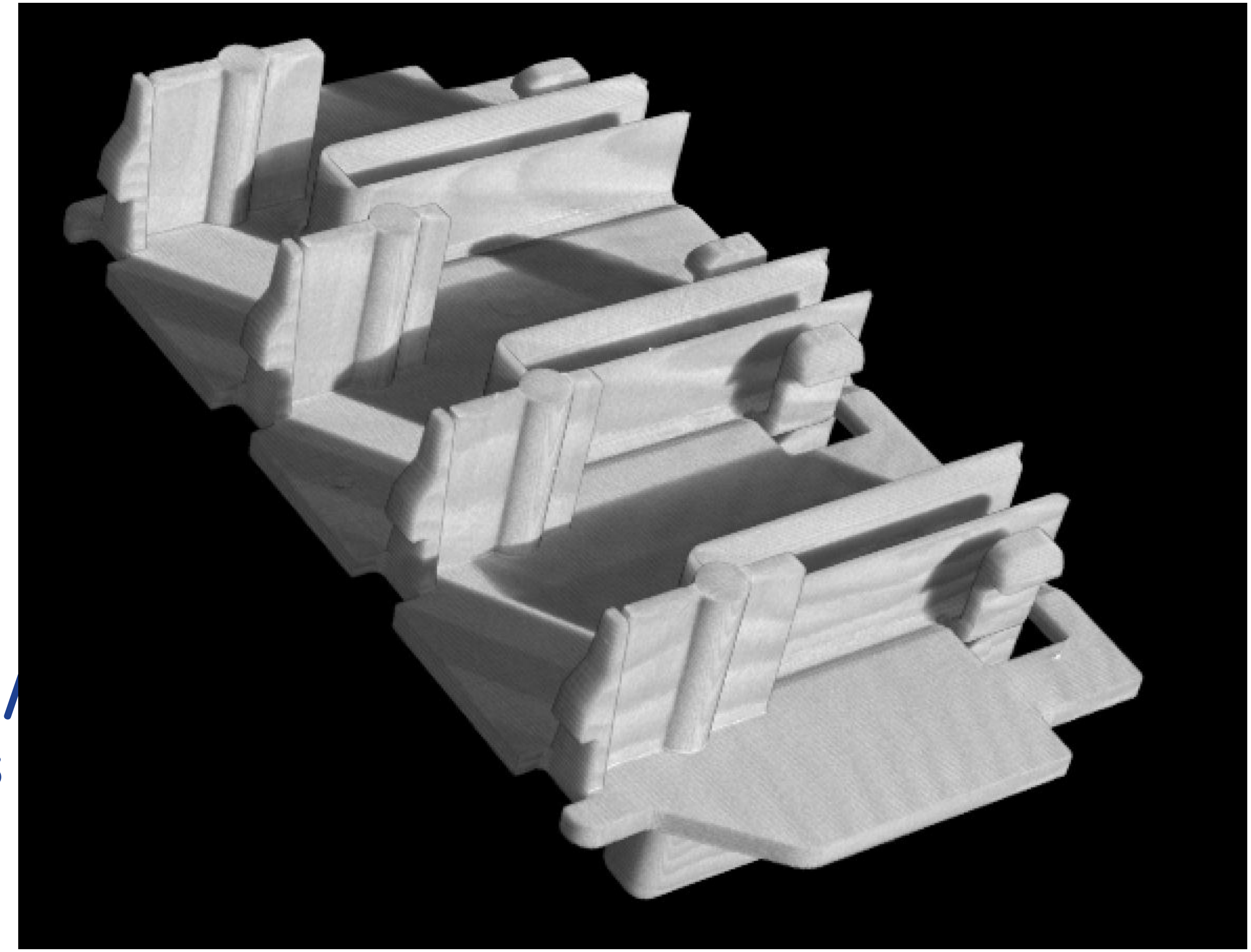
Metrology

Process flow

1. CT Volume data
2. Surface
3. CAD Data
4. Alignment
5. Comparison / Measurements



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Metrology

Process flow

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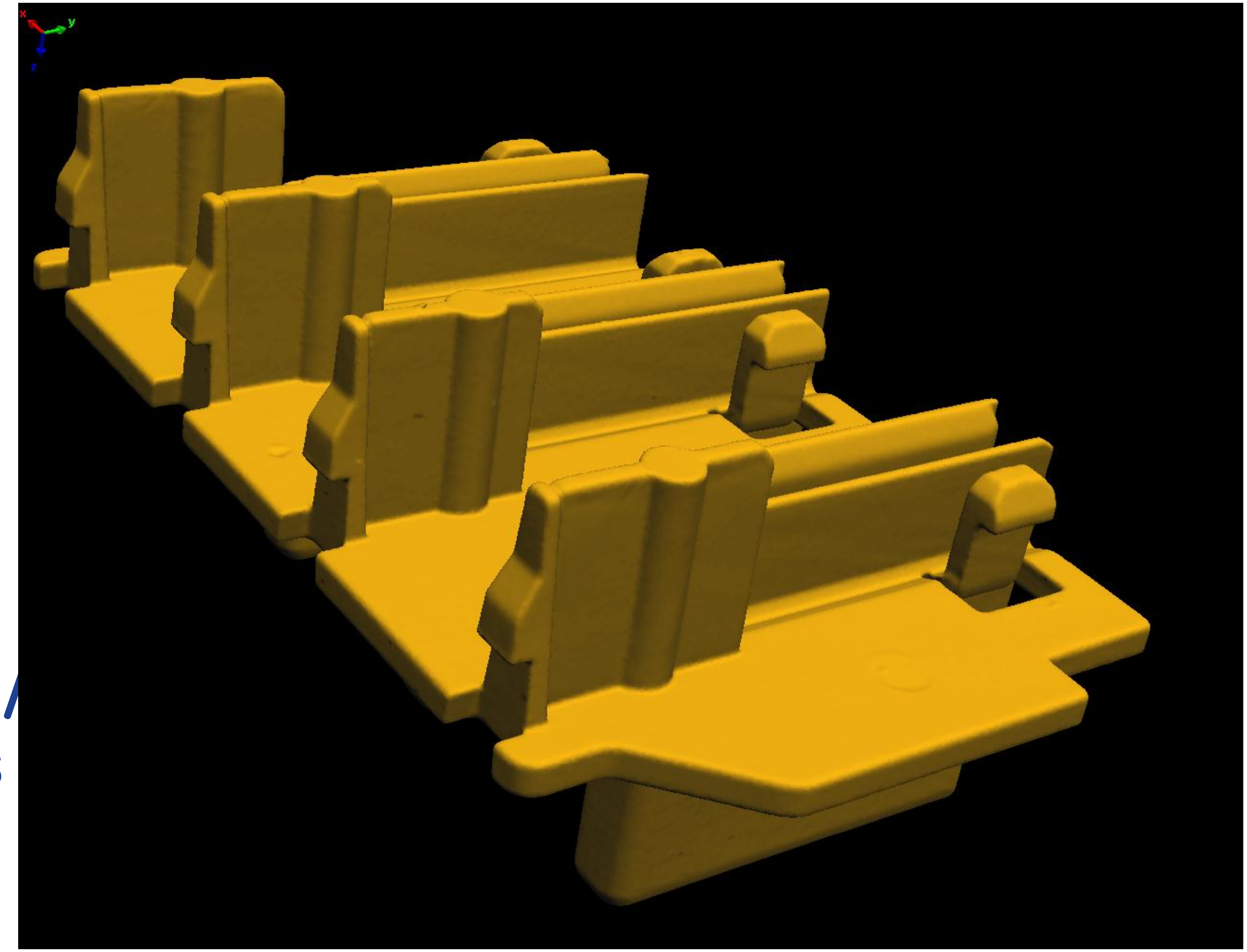

Metrology

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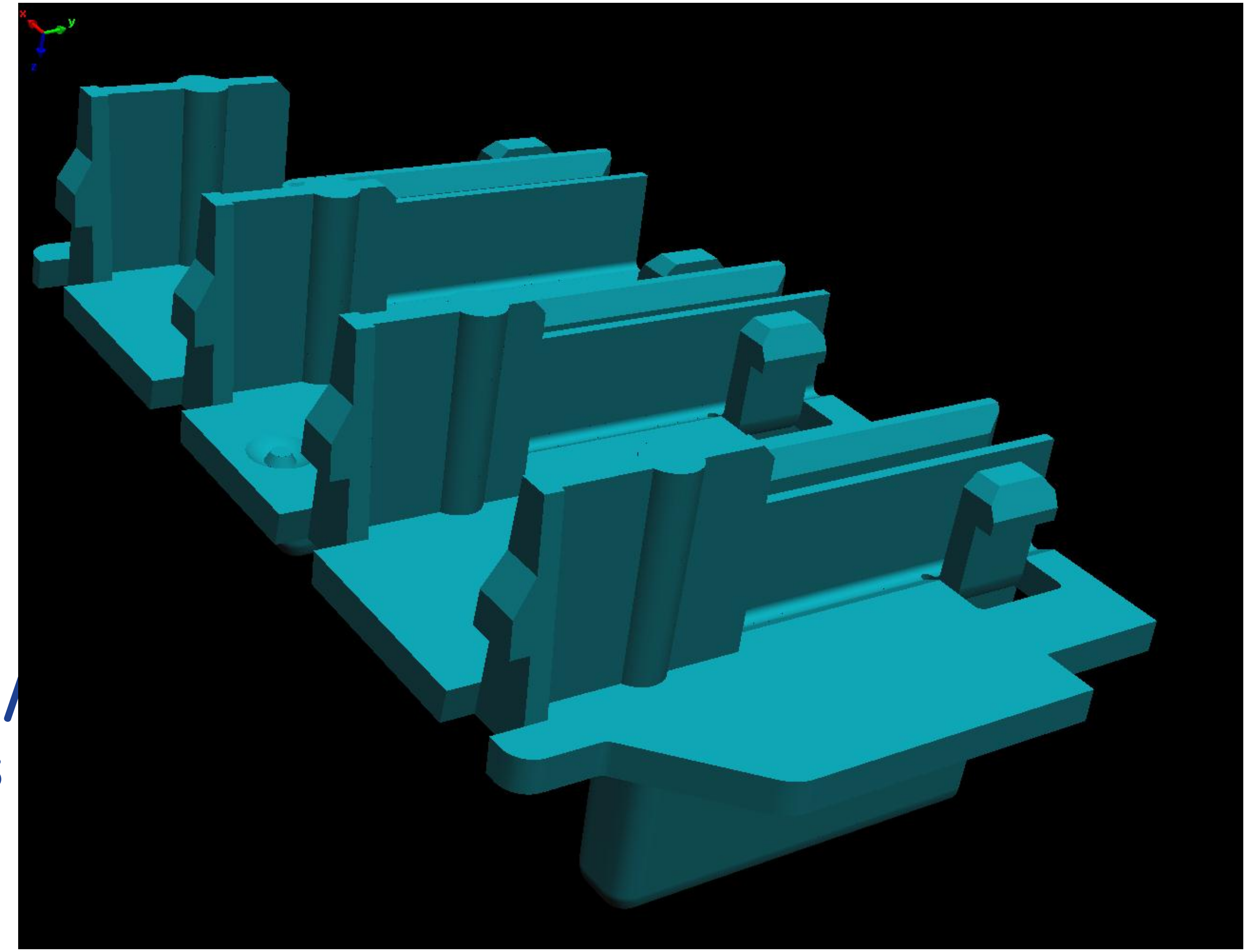

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Metrology

Process flow

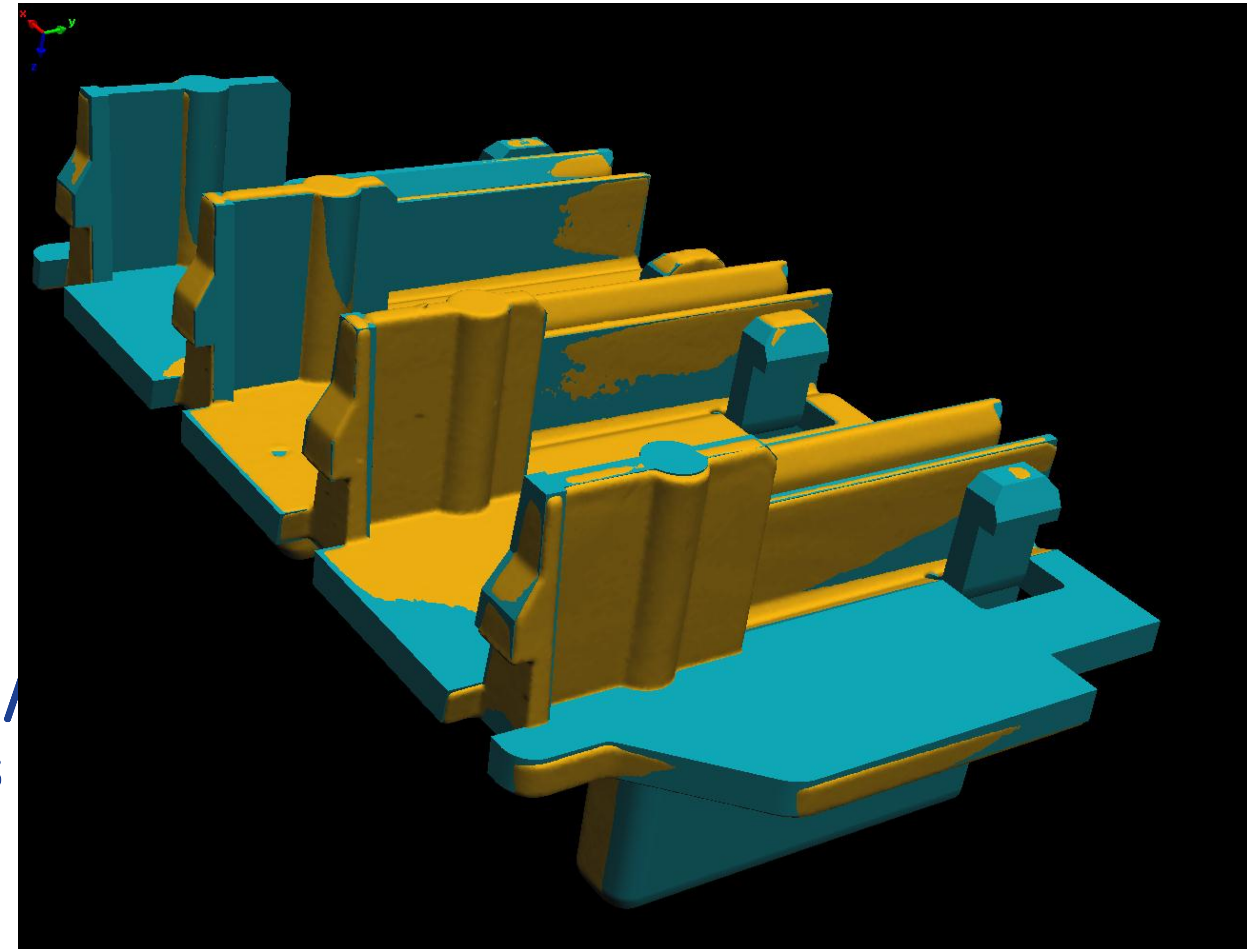
1. CT Volume data

2. Surface

3. CAD Data

4. Alignment

5. Comparison / Measurements

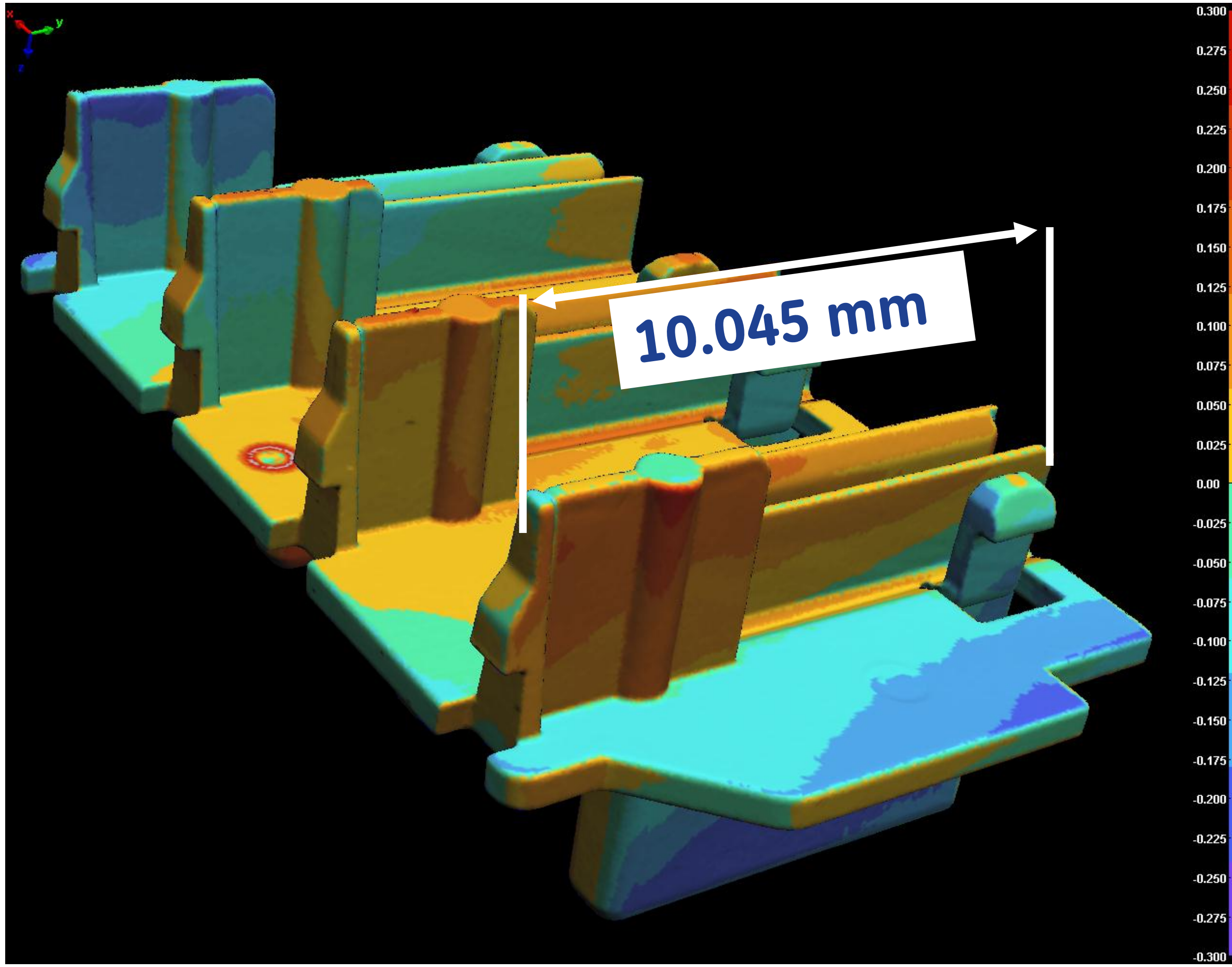


Metrology

Process flow

1. CT Volume data
2. Surface
3. CAD Data
4. Alignment
5. Comparison, Measurements

+300µm above CAD



-300µm below CAD

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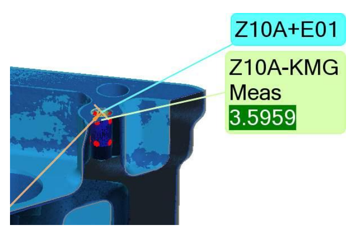
Al casting: CT vs. CMM

Al Cylinderhead model by
ACTech GmbH, Germany

CT system:
phoenix v|tome|x m 300
in air conditioned environment

Reference system:
Hexagon Metrology/Leitz PMM 12106
in certified measurement room class 1

Comparison of ~20 features
distances, diameters



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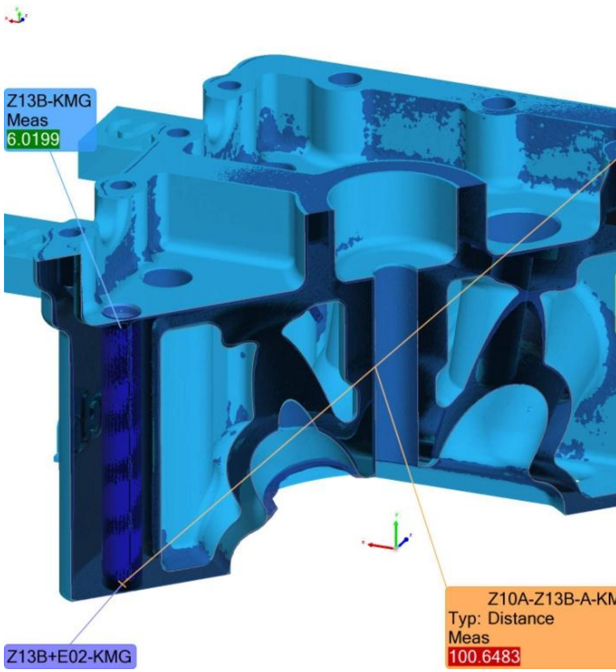
Al Casting: distances comparison

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Kalibrierlaboratorium für Länge / Koordinatenmesstechnik
Calibration laboratory for length / coordinate metrology

Akkreditiert durch die / *accredited by the*
Akkreditierungsstelle des Deutschen Kalibrierdienstes

FEIN MESS

DKD-K-25901

Kalibrierschein
Calibration certificate

Kalibrierzeichen
Calibration mark

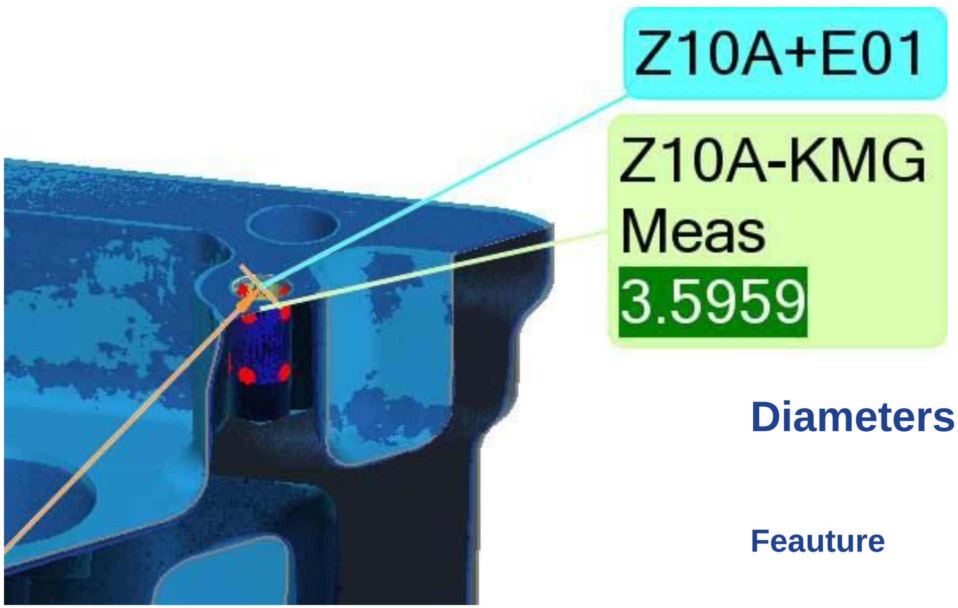
7754
DKD-K-25901
2009-04

Distances

Feature	tactile DKD value	CT value	Dev CT-tactile
1. Z09A-Z09B-A	64,9993	65,0041	0,004
2. Z09A-Z10A-A	20,0094	20,0056	-0,004
3. Z09B-Z10A-A	68,0055	68,0088	0,003
4. Z13A-Z13B-A	88,4336	88,4332	0,000
5. Z10A-Z13B-A	100,6552	100,6476	-0,007

imagination at work

Al Casting: diameter comparison

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DKD-K-25901

Kalibrierschein
Calibration certificate

Kalibrierzeichen
Calibration mark

7754
DKD-K-25901
2009-04

Diameters

Feauture	tactile DKD value	CT value	Dev CT-tactile
1. Z09A-DM	3,5963	3,5956	**-0,001**
2. Z09B-DM	3,5974	3,5952	**-0,002**
3. Z10A-DM	3,5962	3,5959	**0,000**
4. Z10B-DM	3,5949	3,5930	**-0,002**
5. Z13A-DM	6,0153	6,0194	**0,003**
6. Z13B-DM	6,0162	6,0197	**0,003**
7. Z14-DM	7,0033	7,0083	**0,004**

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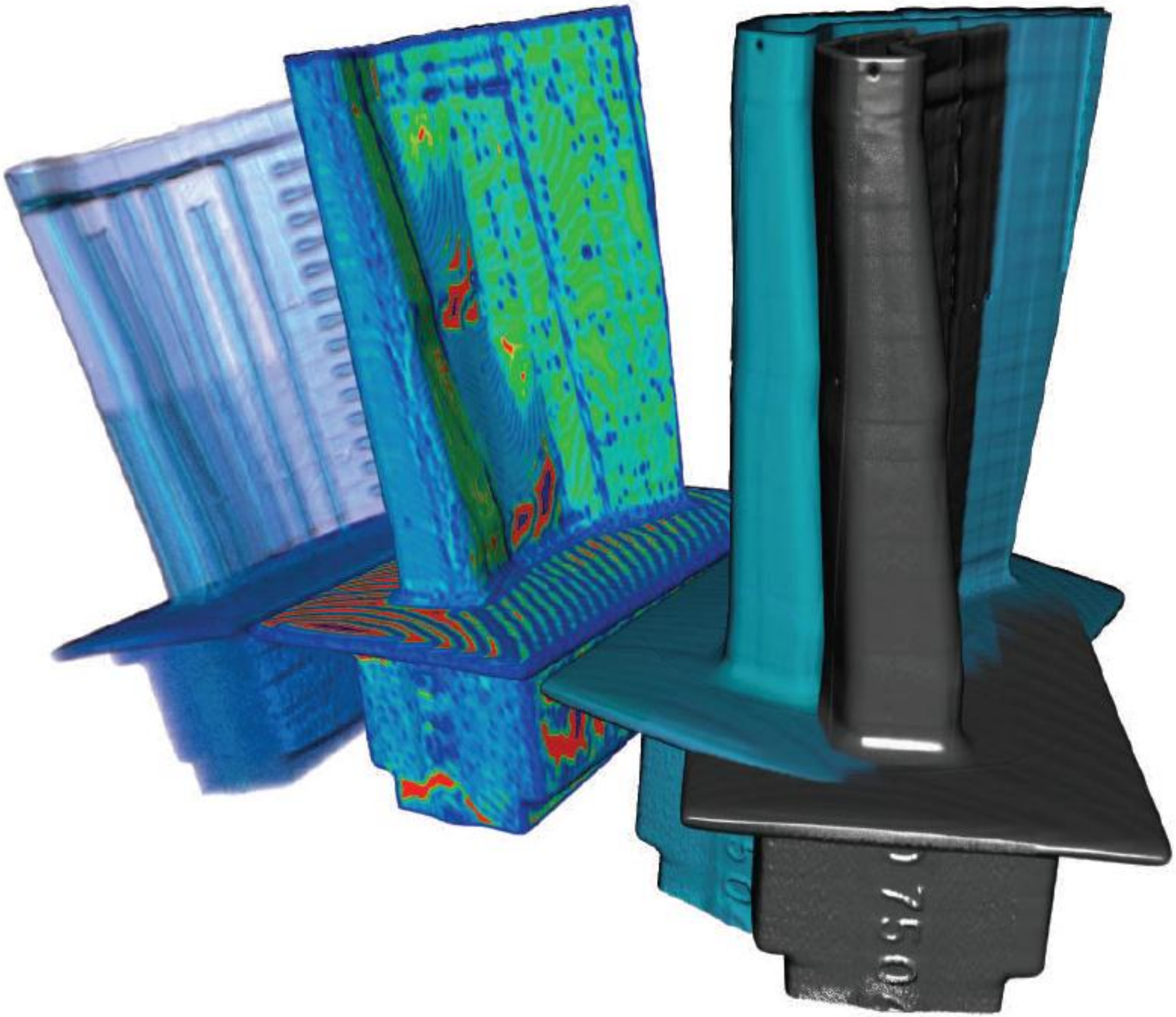
GE Measurement & Control Solutions

Recent advances of high-resolution CT

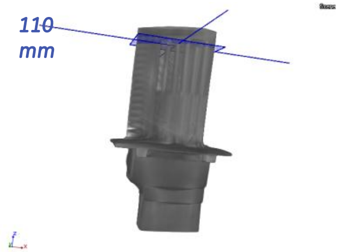
GE imagination at work

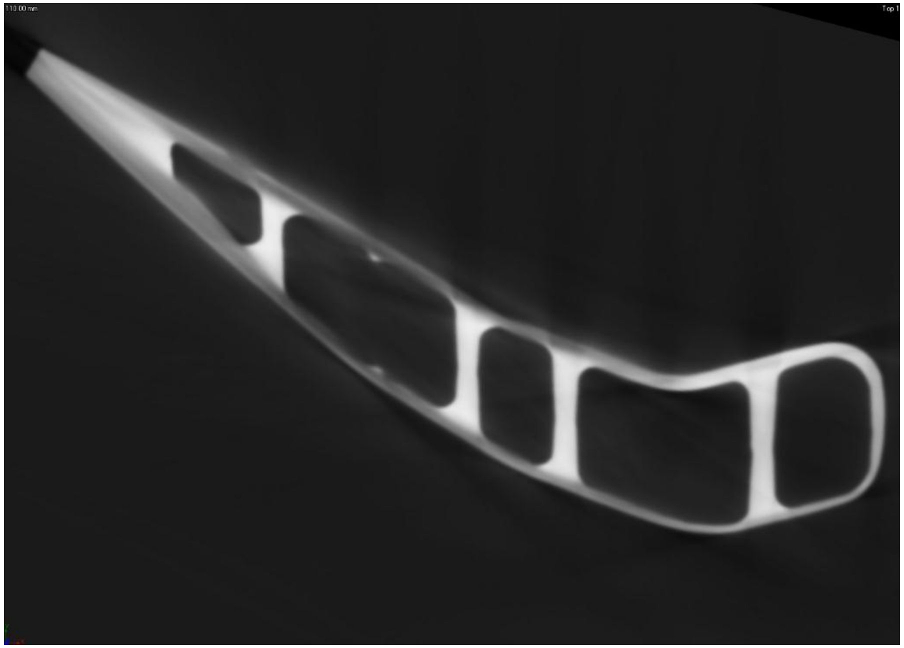
CT for turbine blade inspection



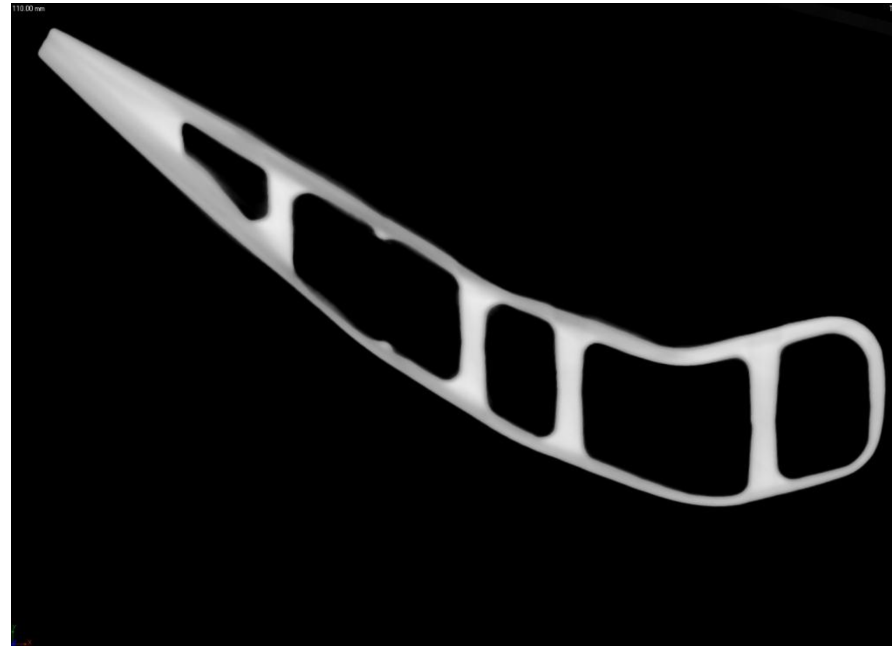
UNIPOLAR 300 kV microfocus X-ray tube

- max. voltage: 300 kV
- unipolar design, FOD < 5 mm
- max. power: 500 W
- focal spot size: 3 – 200 µm





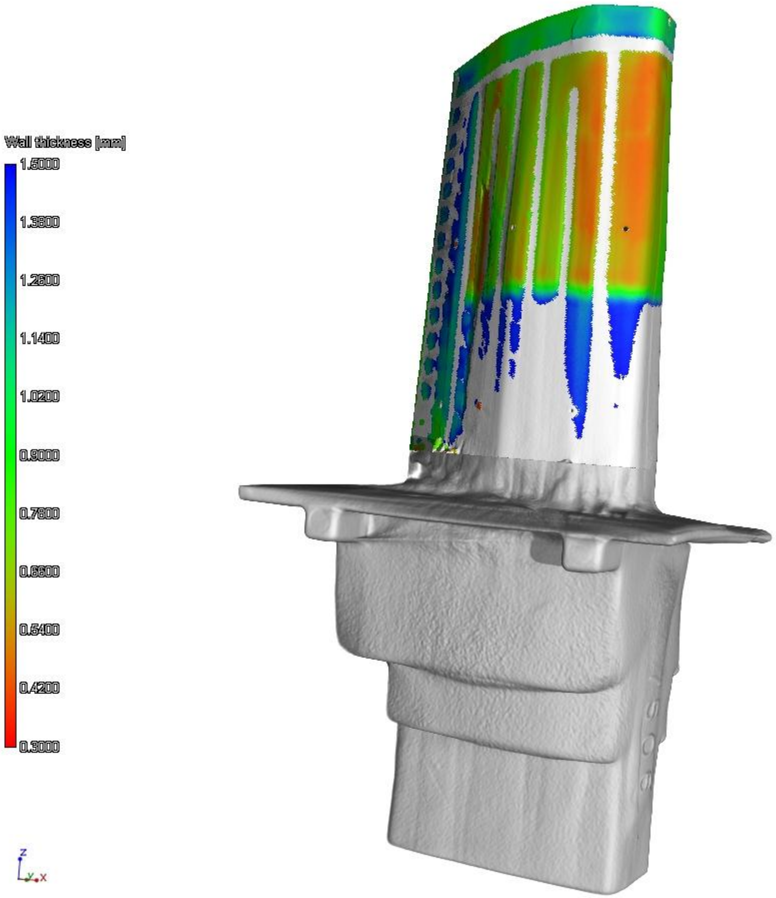
225kV

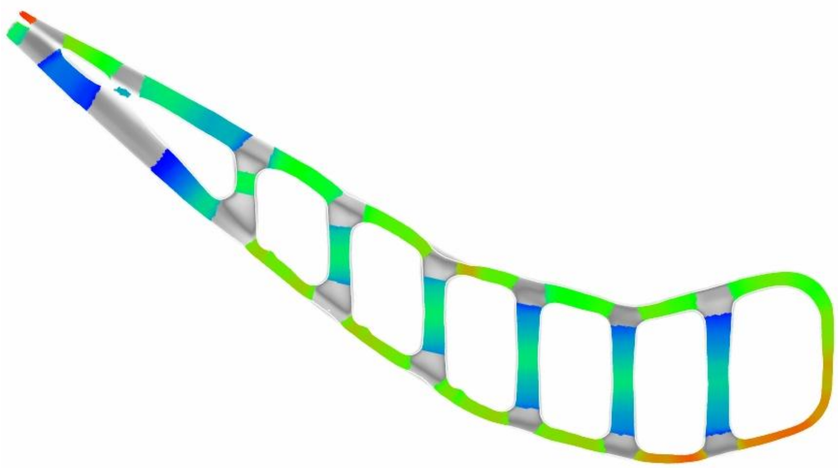


300kV

>>> Reduced artifacts: increased global gray value homogeneity allows higher measurement accuracy

imagination at work

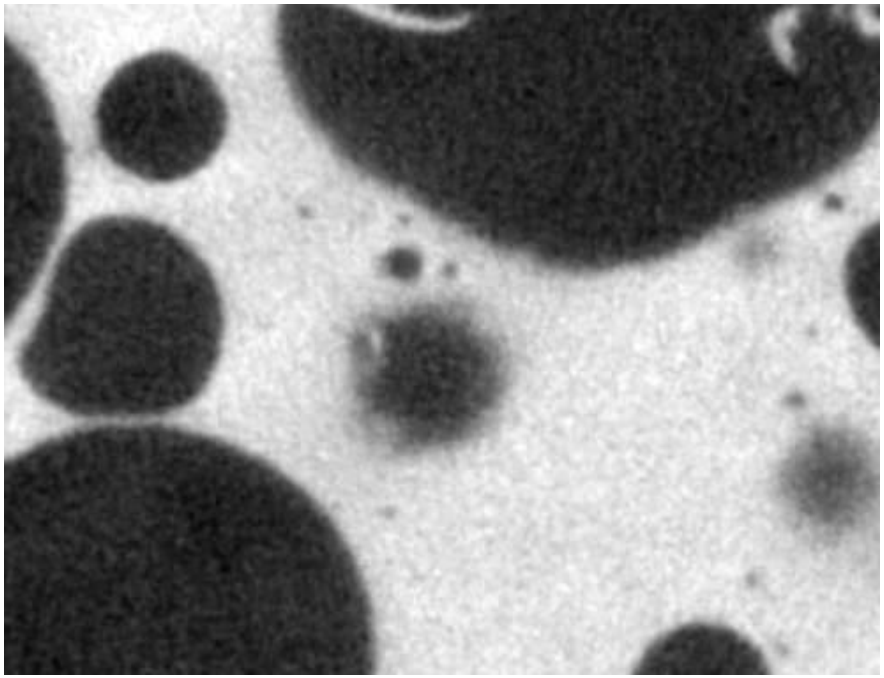




Example for wall thickness measurements on a jet engine turbine blade with v|tome|x m 300

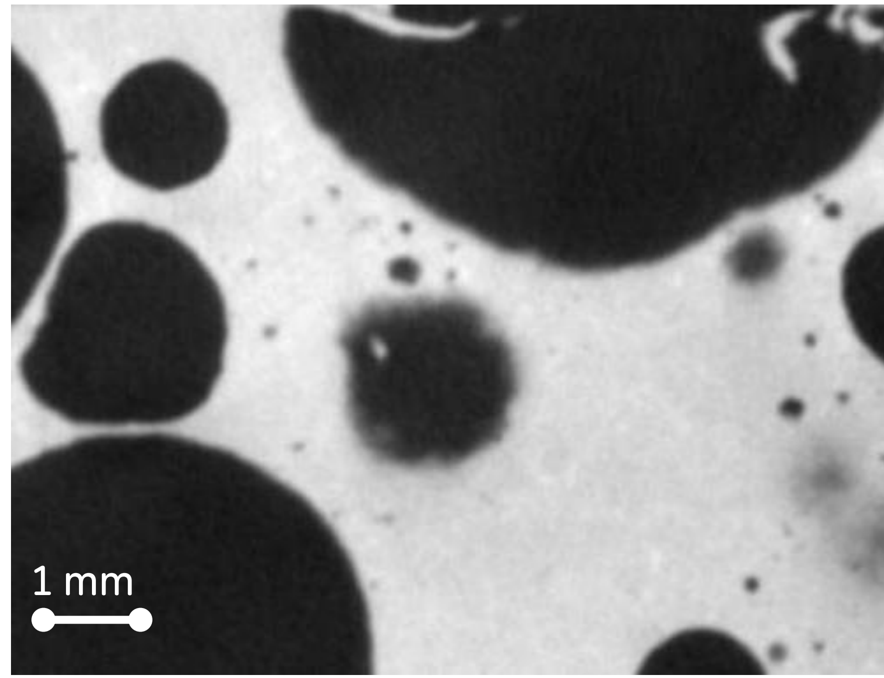
CT for materials science

State of the art



V = 15 µm, 100kV, 470µA, Mode 0, 1h

nanotom m



V = 15 µm, 100kV, 470µA, Mode 0, 1h

Improved sharpness (+80%) & increased CNR (+100%) due to diamond window and low noise detector.

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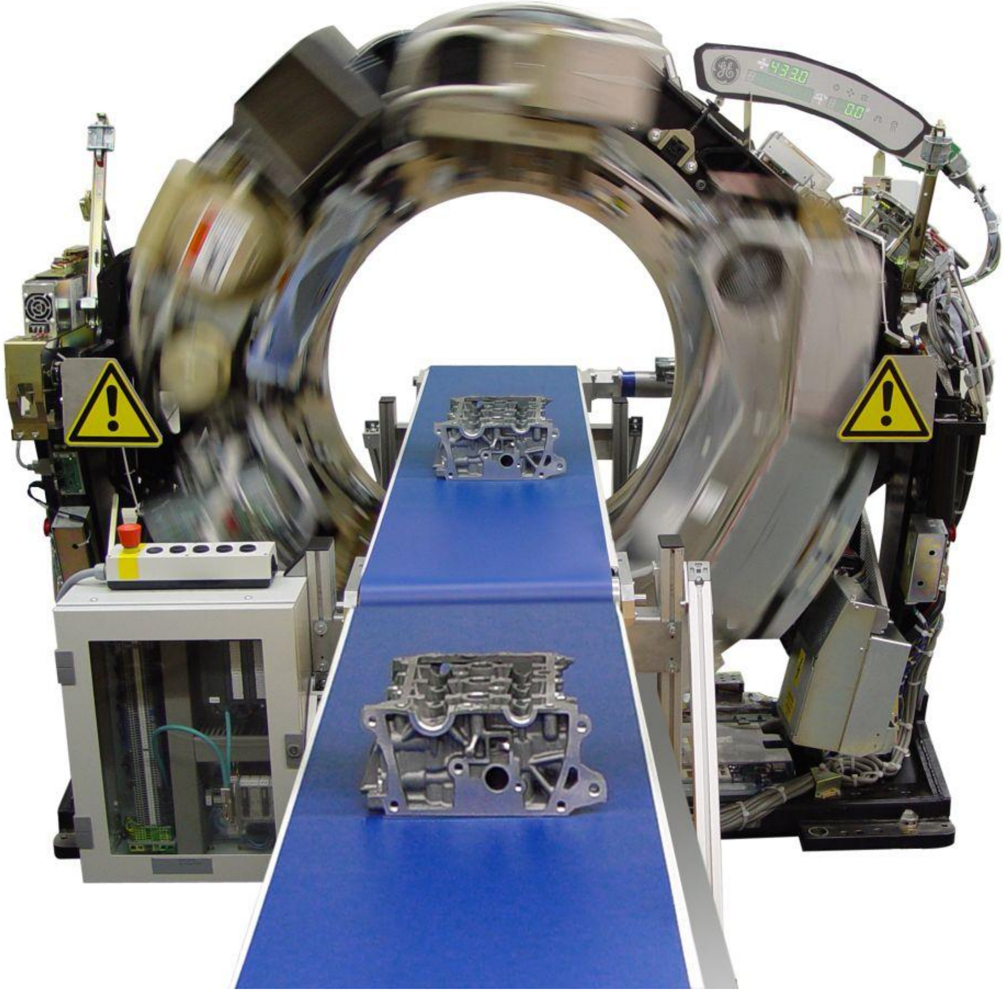
GE Gantry based CT for fast 3D industrial part inspection



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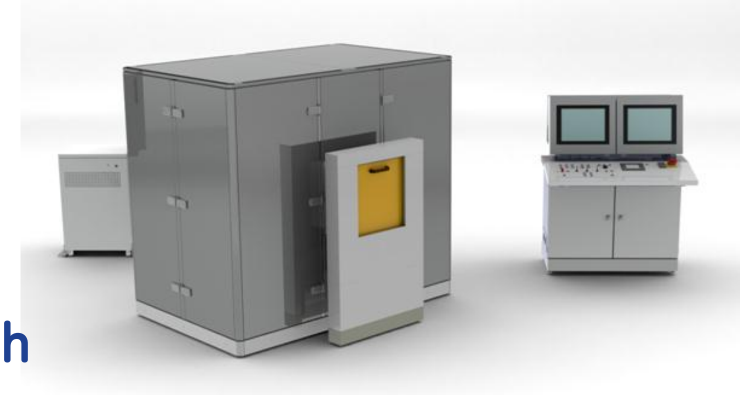
GE AtlineCT overview

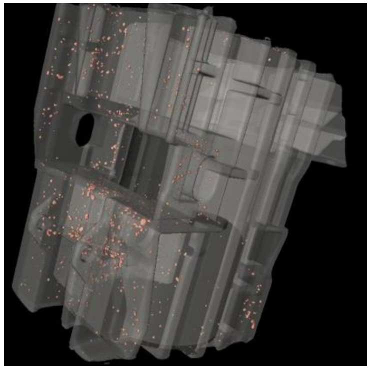


Inspection volume:
400mm width x 300mm height x 800mm length
Up to 50kg sample weight

Scan- and inspection times:
5-10mm/s
-> 10-60s for typical castings

Spatial resolution:
≥ 300µm
->min. detectable defect size: >0.5 mm

Penetration length:
up to 300mm Al



GE 3D automatic defect analysis and -classification

Designed for operation in harsh environments (foundries)

Belt conveying system

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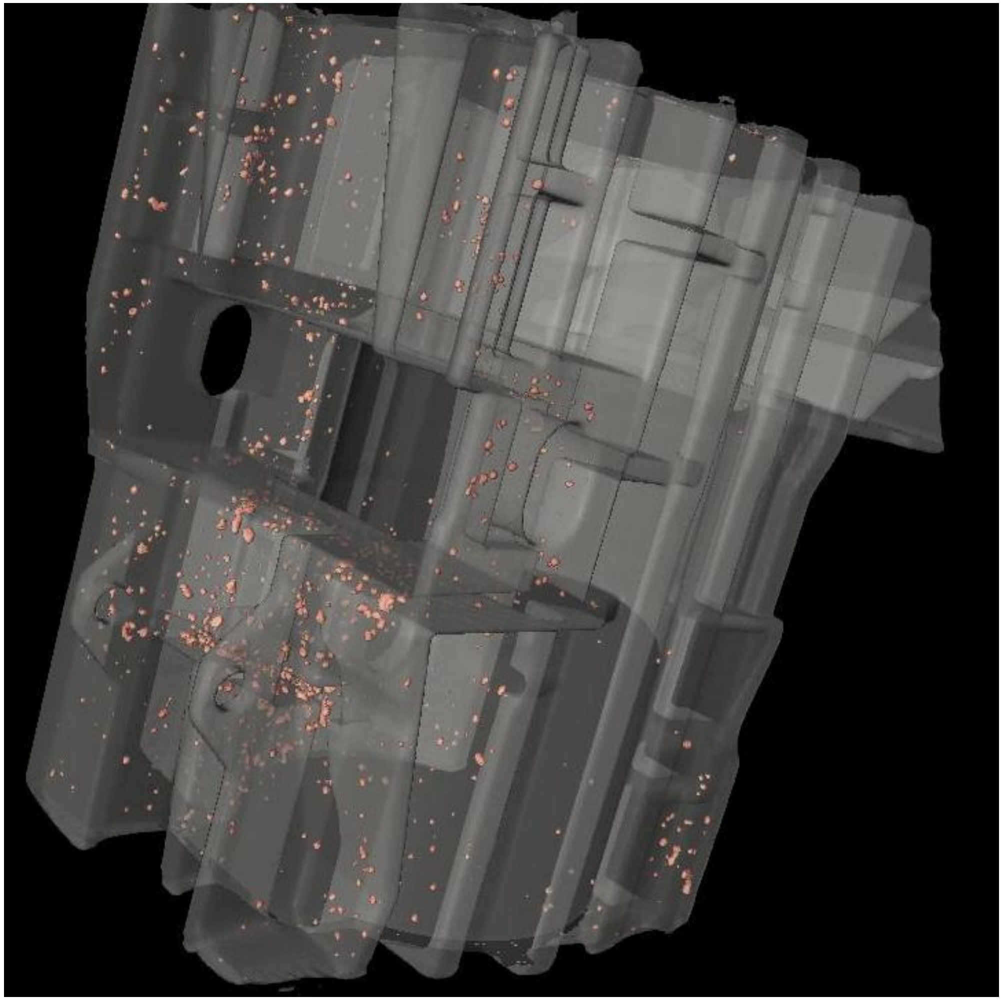
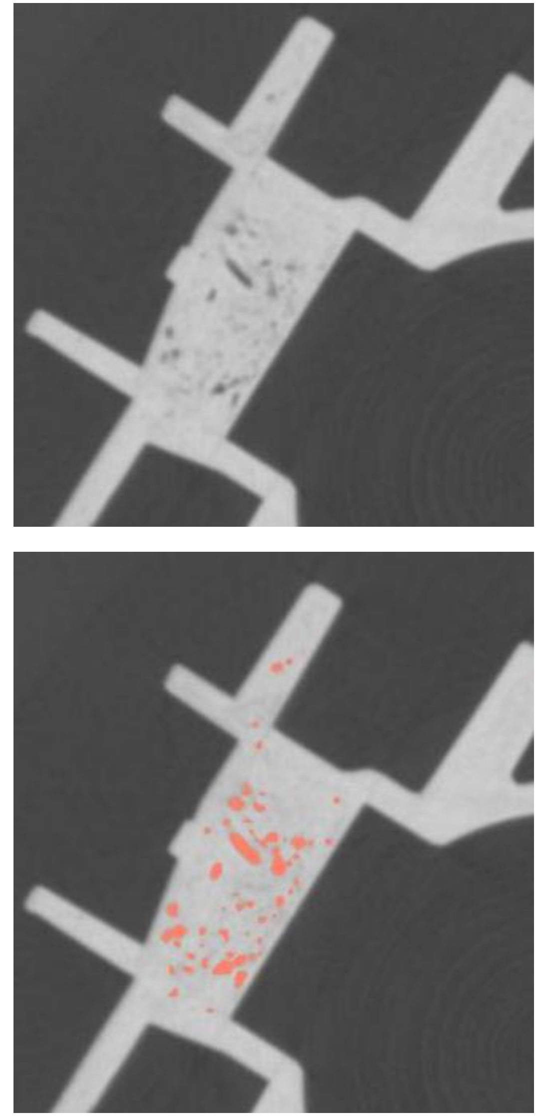
GE 3D Automatic Defect Detection





Result on a die casting, 5 s defect detection time

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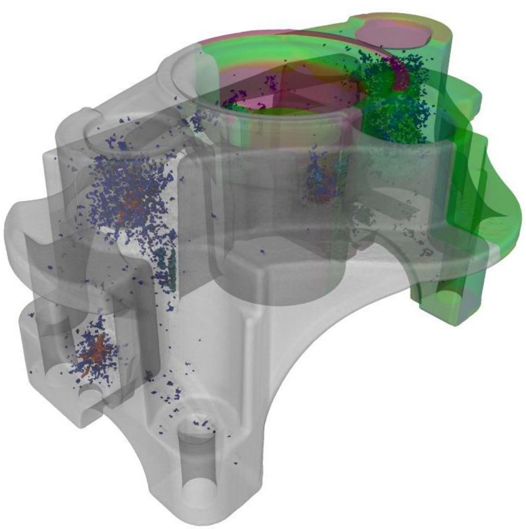
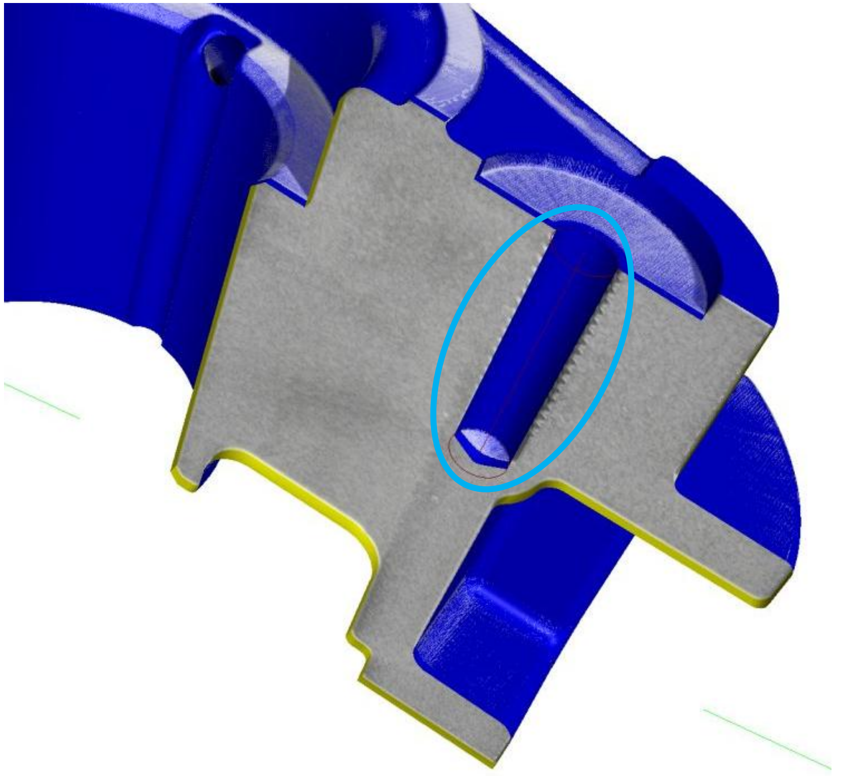
Automated 3D inspection with CT

Usage of CAD-models

Detection of part deviations and defects in 3D

- Actual-Nominal-Comparison (part deviations)
- Comparison to admissible tolerances
- Compare with CAD-Data of machined part
- Defect unearthing after machining
- Wall thicknesses after machining





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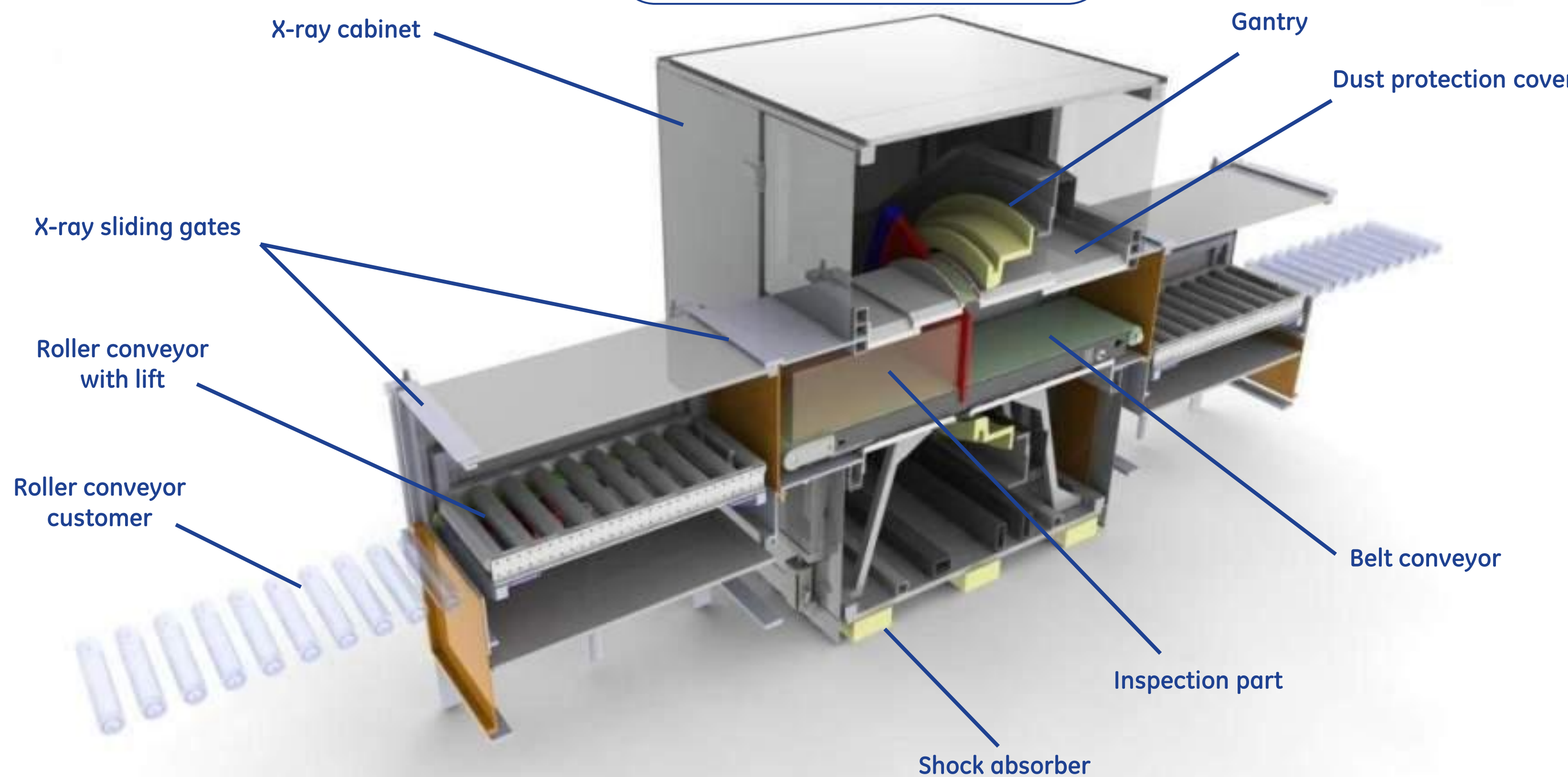
GE InlineCT Setup

3D-ADR Image Processing
Automatic workflow for unmanned operation



Mila esker!

Grazie mille!

¡Muchas gracias!

Merci beaucoup!

谢 谢!

Muito obrigado!

תודה רבה!

धन्यवाद धन्यवाद!

END

Many thanks for your kind attention!

Mange tak!

شكرا جزيلا!

Vielen Dank!

Большое спасибо!

Tack så mycket!

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どうもありがとうございます!

High-resolution X-ray computed tomography

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or

www.ge-mcs.com/phoenix

“I find out what the world needs. Then I go ahead and try to invent it.”

Thomas A. Edison
Founder, GE

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