Manufacturing Technology Centre

AM INSPECTION / NDT: IS XCT THE SOLUTION?

Dr. Nick Brierley

Principal Research Engineer
Metrology & NDT Group

nick.brierley@the-mtc.org

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OUTLINE

- Challenges of AM post-build inspection
- XCT for AM
- Current limitations of XCT
- Commercial developments on XCT
- Work at MTC on XCT
- Remaining challenges for XCT
- Alternatives to XCT
- Conclusions
- Questions

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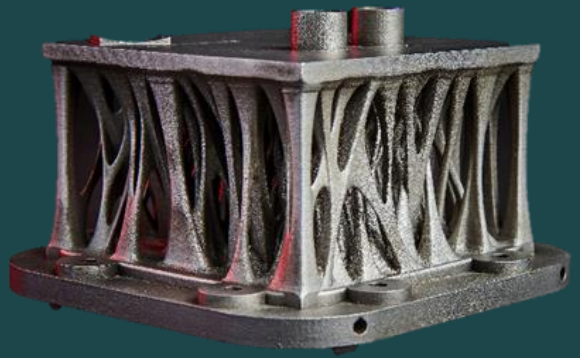
CHALLENGES OF AM POST-BUILD INSPECTION (1)

- Geometric complexity of parts
  - Additive Manufacturing (AM) enables design complexity
- Poor surface finish
  - Depends on processing route

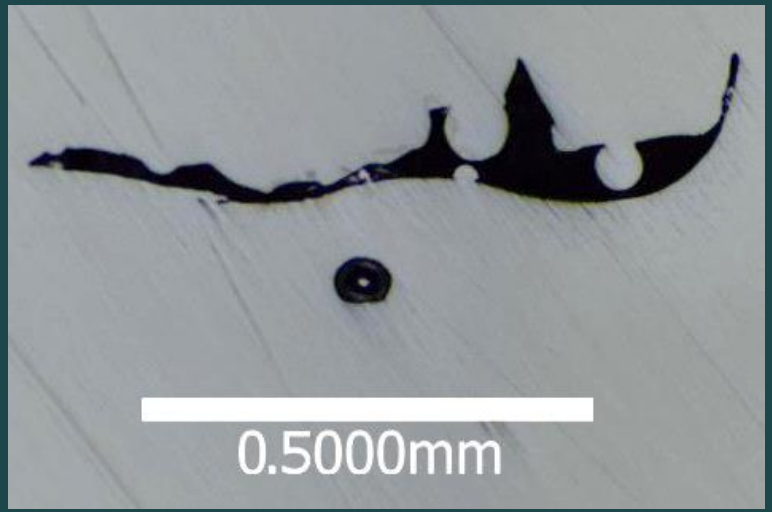


Laser powder bed part, courtesy of 3T RPD Ltd

EBM part, made by MTC

CHALLENGES OF AM POST-BUILD INSPECTION (2)

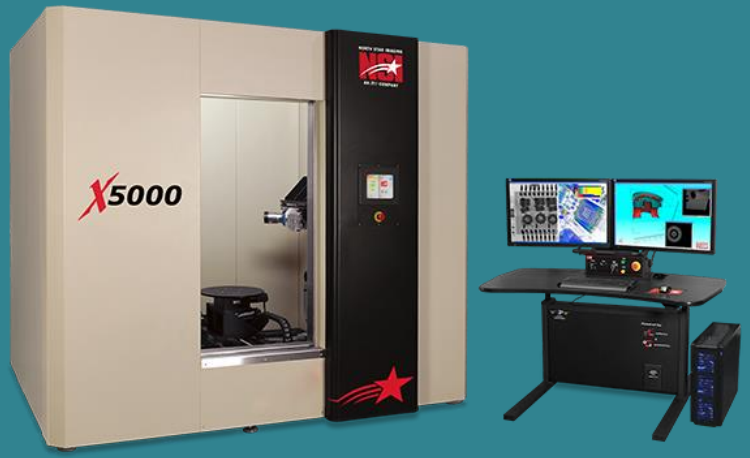
- Geometric complexity of defects
  - Process-specific
- No intermediate manufacturing stages
  - E.g. geometrically simple billet
- Challenges largely also relevant to other net shape manufacturing processes
  - Hot Isostatic Pressing (HIP)
  - Metal Injection Moulding (MIM)
  - Casting



Pores found in cut-up of an EBM part
Courtesy of Rolls-Royce
© Rolls-Royce 2014

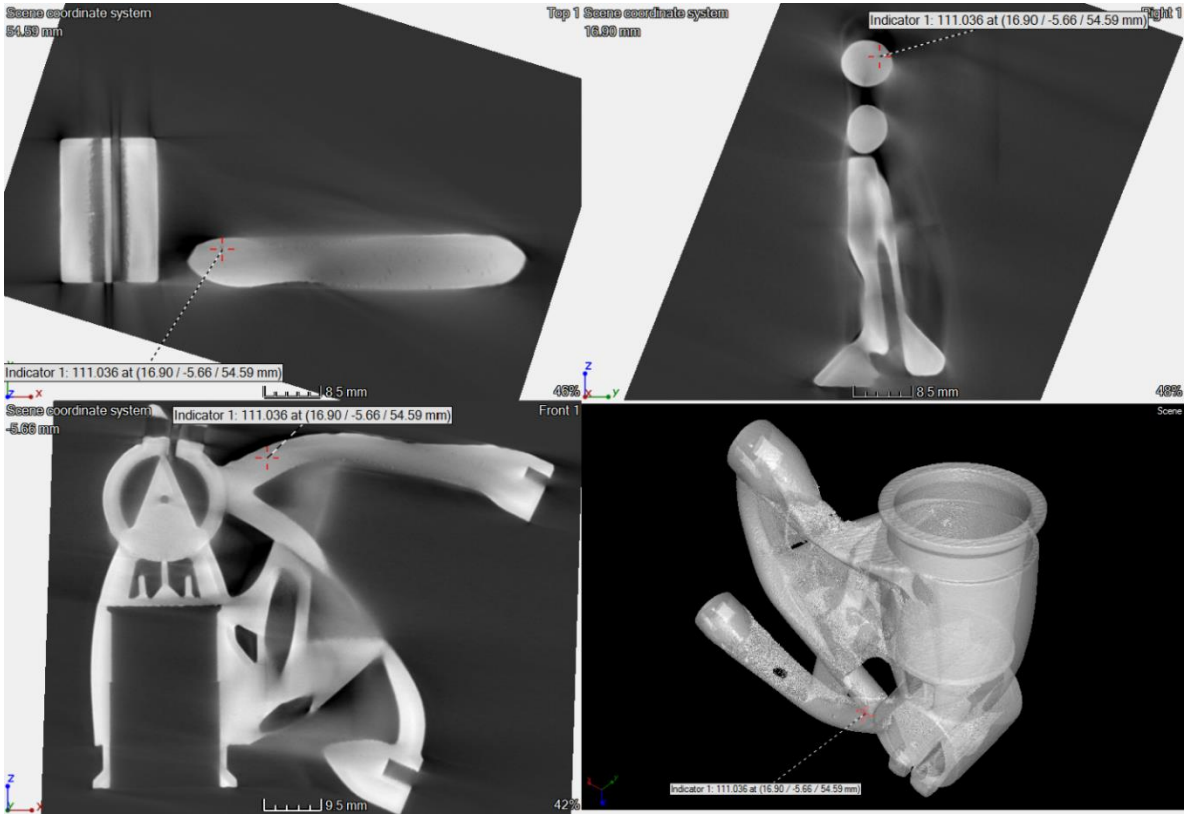
X-RAY COMPUTED TOMOGRAPHY (XCT) FOR AM (1) Advantages

- Full volume
- Non-contact
  - Operation independent of surface condition
- Operation essentially independent of geometric complexity
  - Detailed 3D information provided
- Information about geometrical conformance
  - Dimensional metrology



From http://4nsi.com/systems/x5000

X-RAY COMPUTED TOMOGRAPHY (XCT) FOR AM (2) Example



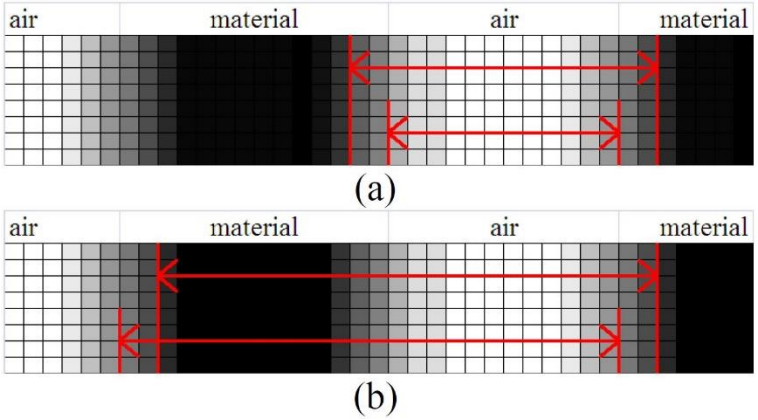
Steel AM test sample made at MTC. Sample geometry courtesy of GRM Consulting Ltd.

CURRENT LIMITATIONS OF XCT (1)
General

- XCT is not without limitations:
  - Need to fit part into enclosure
  - Need to able to fully rotate part
  - X-rays need to be able to penetrate the part
  - Cycle times relatively long
  - Inspection costs are relatively high
  - Spatial resolution decreases with sample size
  - Reconstruction artefacts & noise can mask features of interest
  - Data volumes generated can be overwhelming
  - Quantitative inspection performance not well understood
  - Lack of inspection standards, official personnel training & certification
- Some limitations are permanent features of the technology

CURRENT LIMITATIONS OF XCT (2) Metrology

- There are additional limitations related to dimensional metrology:
  - Many sources of uncertainty, most not fully understood
  - Lack of traceability & comprehensive standards
  - The segmentation / surface determination in analysis of XCT data has potential to substantially affect inspection performance



Edge dependent (a) and edge independent distances (b). From Kiekens, K. et al., 2011. Parameter Dependent Thresholding for Dimensional X-ray Computed Tomography. *International Symposium on Digital Industrial Radiology and Computed Tomography.*

COMMERCIAL DEVELOPMENTS (1)
High-speed XCT

From zeiss.co.uk

Zeiss VoluMax:
Robotic part loading & unloading, fast scan sequence using shuttered beam

From gemeasurement.com

GE speed|scan CT 64:
Helical medical scanner design with rotating gantry

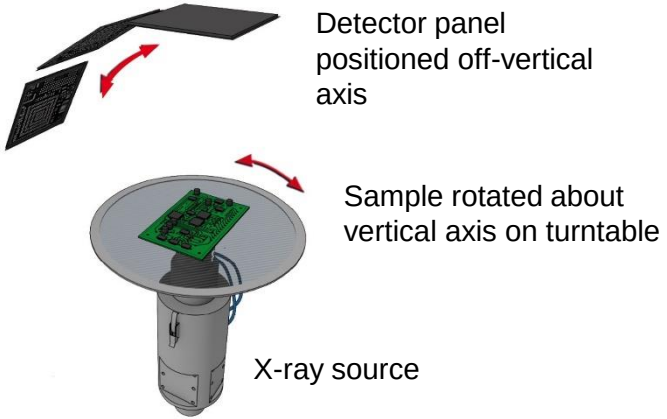
- Different approaches to achieving fast cycle times

From rapiscansystems.com

Rapiscan RTT 110:
High-speed baggage scanner using multi-source, stationary gantry

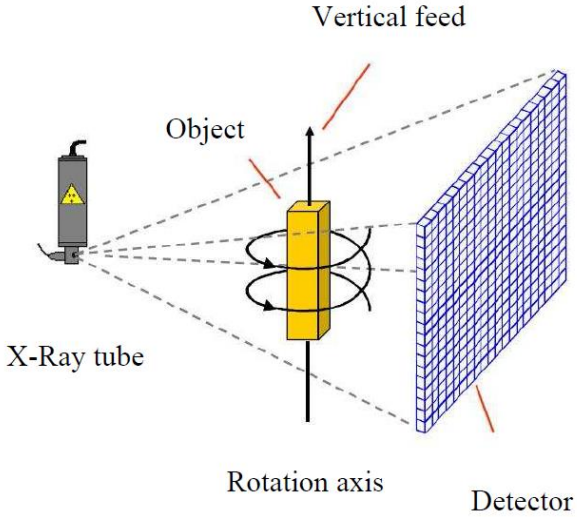
COMMERCIAL DEVELOPMENTS (2)
Flexible XCT

- Laminography
  - For largely flat specimens



From nikonmetrology.com

- Helical Scanning
  - For elongated specimens



From Voland et al., Computed Tomography (CT) system for automatic analysis of ice cores, ECNDT 2010

COMMERCIAL DEVELOPMENTS (3)
Metrology XCT

- Systems enhanced for stable & accurate dimensional metrology

From yxlon.com

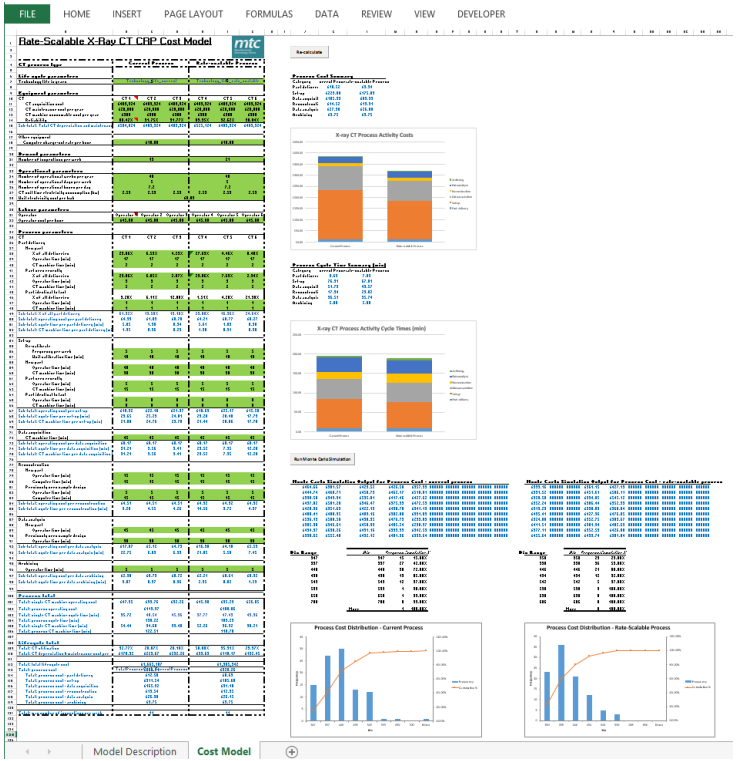
Yxlon FF35:
Precision granite-based manipulator, temperature stabilisation – plus multiple scanning trajectories and active collision protection

From gemeasurement.com

GE phoenix v|tome|x m:
Precision granite-based manipulator, temperature stabilisation - plus scatter|correct

WORK AT MTC (1)
XCT Cost Model

- Interactive cost model for XCT inspection process flow created
  - Computes per part & machine lifecycle costs
  - Designed to allow two configurations to be compared
  - Allows users to determine what changes could help lower costs
- Inputs required include:
  - XCT system costs
    - Capital
    - Maintenance
    - Consumables
  - Inspection demands
    - Rate
    - Variability
  - Timings of process stages
  - Operator hourly rate
  - Data archiving costs



WORK AT MTC (2)
Simultaneous Inspection

- Investigation into scope for using a XCT scan for both integrity & dimensional inspections
  - A means of addressing frequent cost & time concerns
- 3 inspection strategies considered & analysed:
  - XCT in isolation
  - XCT plus data from master part
  - XCT plus (limited) conventional metrology
- Also examined possibility of co-locating XCT & optical / tactile measurements

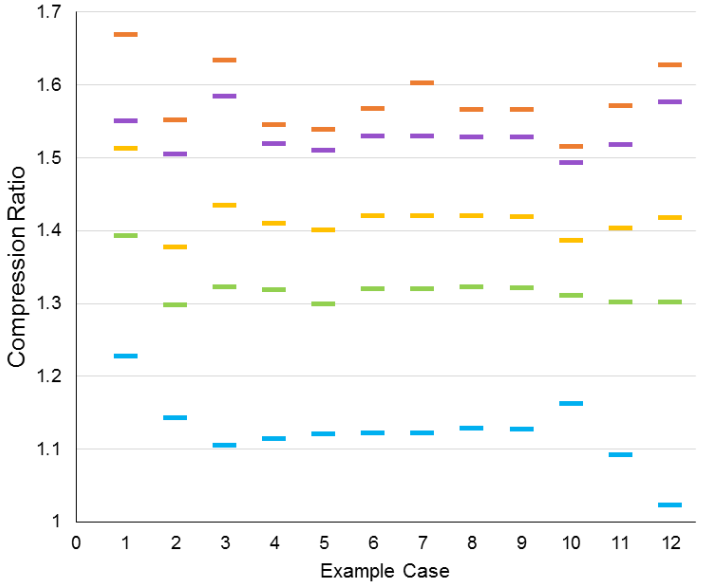
From werth.de

Werth Tomoscope HV Compact:
Multi-sensor Coordinate Measurement Machine (CMM), here combining tactile & XCT measurements

WORK AT MTC (3)
XCT Data Management

- Examination of potential integration of XCT data into Product Lifecycle Management (PLM) systems
  - For improved traceability and data exploitation
- Assessment of approaches for managing XCT data volumes, covering:
  - Selective retention of projection images & XCT volume datasets
  - Compression algorithms for “squeezing” images & volumes

Results from trials on different compression algorithms applied to projection datasets



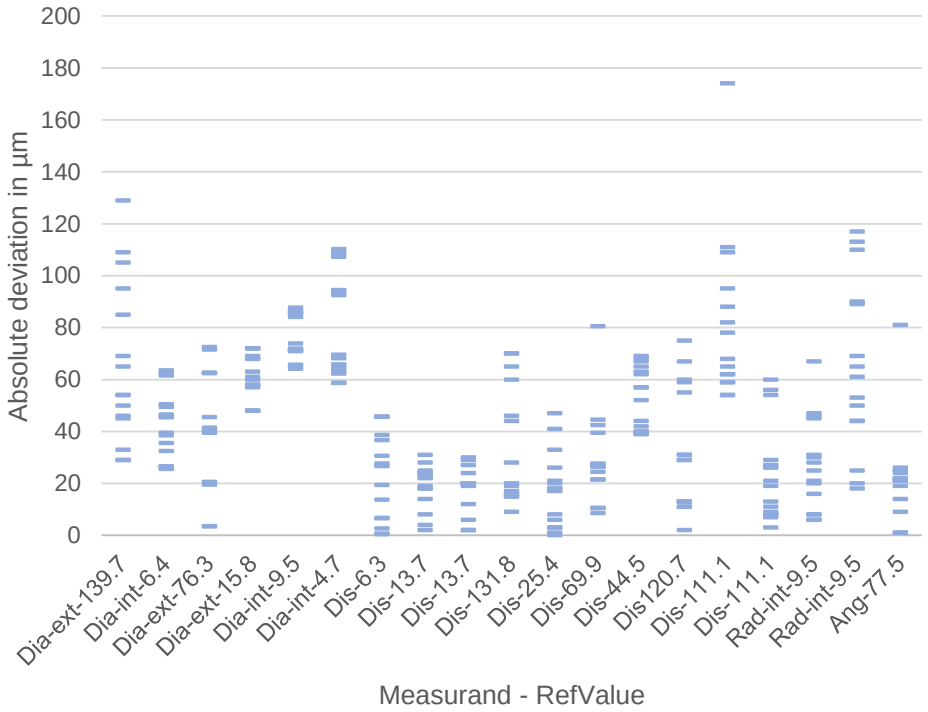
WORK AT MTC (4)
XCT Metrology Assessment – Overview

- Study of the capabilities of XCT for dimensional measurement on 3 industrially relevant artefacts:
  - 3D-printed polymer (ABS)
  - Aluminium
  - Nickel super-alloy
- Tactile CMM reference data used
- Collected 3 repeats for each artefact on 5 XCT systems:
  - Nikon XTH 225 ST (non-metrology)
  - Nikon MCT225
  - Yxlon FF35
  - Zeiss Metrotom 1500
  - GE v|tome|x m300
- Surfaces extracted as .stl files using macros in VG StudioMax 2.2
- Measurements determined from template in PolyWorks

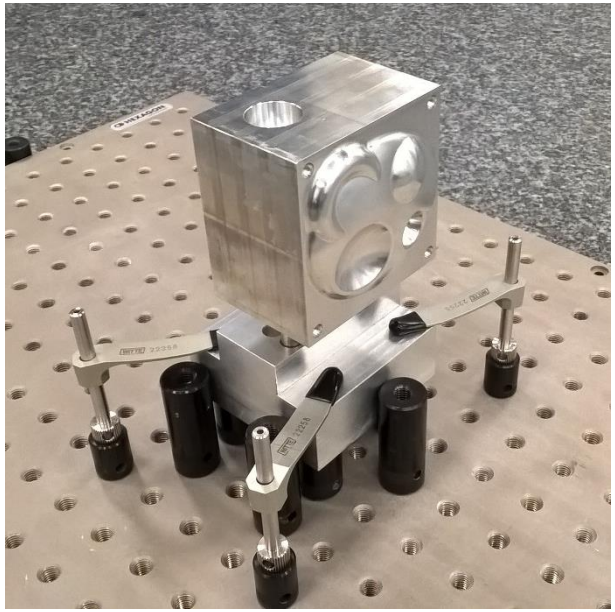
WORK AT MTC (5)
XCT Metrology Assessment – Polymer Artefact

Polymer artefact: MTC modified version of open National Institute of Standards and Technology (NIST) design, 3D-printed in ABS on Stratasys Objet 1000 machine

Results overview for polymer artefact – metrology systems only

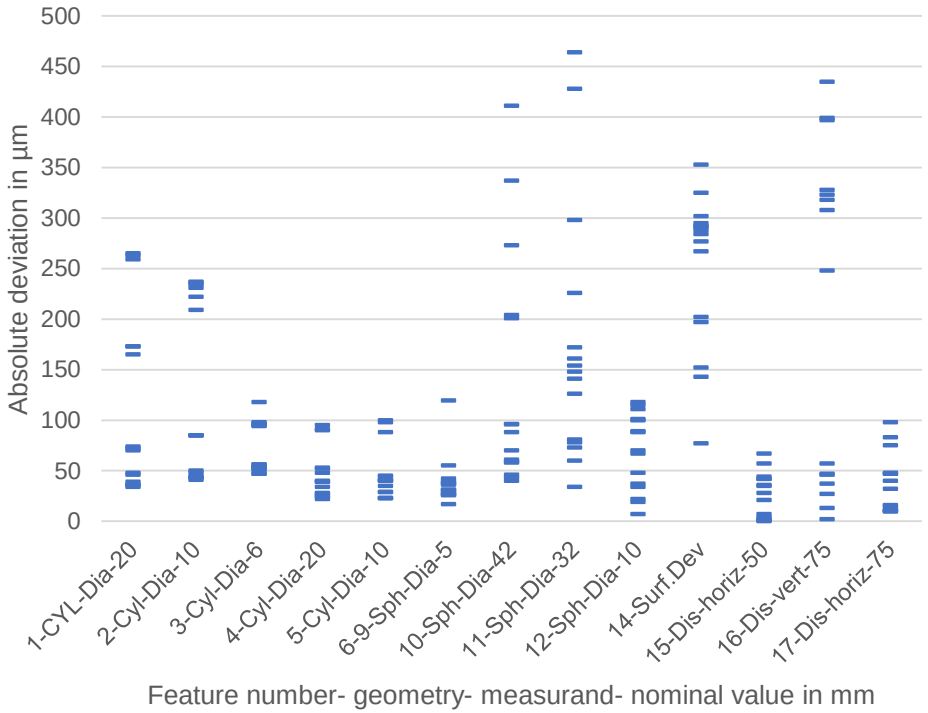


WORK AT MTC (6)
XCT Metrology Assessment – Light Metal Artefact

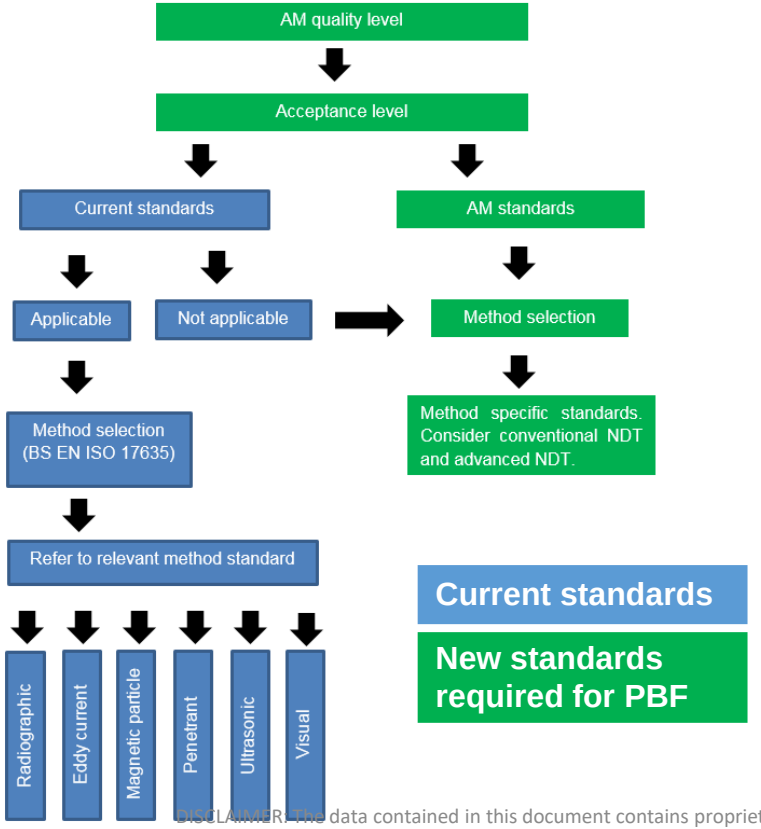


Aluminium artefact (on tactile CMM fixture): customised version of 75 mm National Physical Laboratory (NPL) Freeform Artefact for optical systems.

Results overview for aluminium artefact – metrology systems only



WORK AT MTC (7)
ISO/ASTM NP 52905 Input



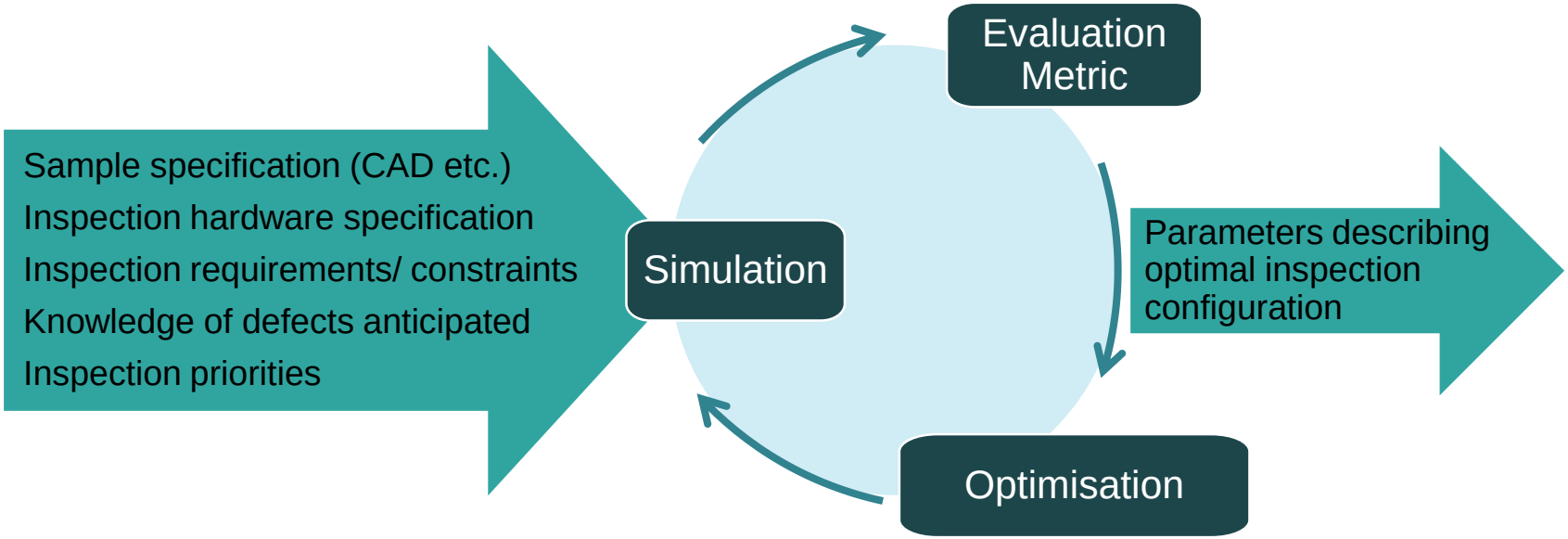
- Approach:
  1. Catalogue AM defects
  2. Review current NDT standards (casting & welding)
  3. Propose NDT methods with potential to detect defects found in AM only
  4. Provide a structure of NDT practices to follow for AM that can be applied to metals and non metals.
- Flow chart shows standard selection structure

REMAINING CHALLENGES FOR XCT

- Industrial understanding of capabilities & limitations of XCT
- Official standards, personnel training & certification for XCT
- Efficient scan & analysis set-up for variable parts
- Efficient data management
- Validation of automated data analyses
- Comprehensive quantitative understanding of inspection performance, both for structural & dimensional purposes
- More flexible scanning & reconstruction
- Faster scanning without compromising output quality
- Improved dimensional metrology performance

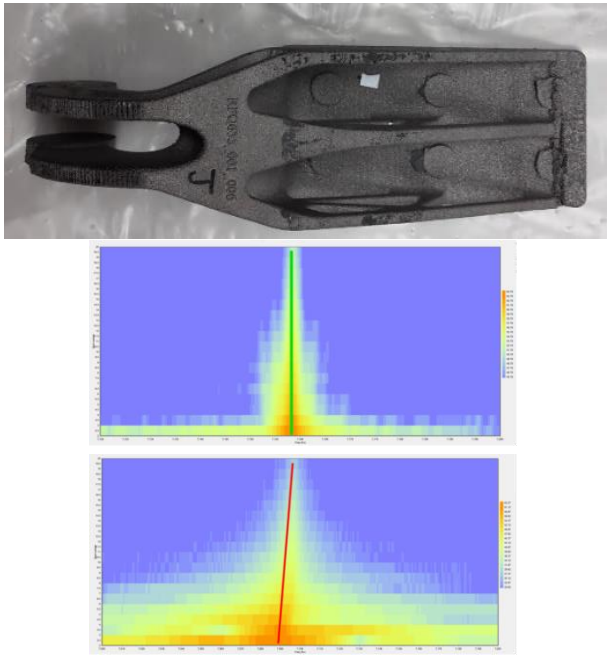
ALTERNATIVES TO XCT (1)
Advanced 2D Radiography

- Use of simulation to improve inspection capabilities
- Active area of research at MTC



ALTERNATIVES TO XCT (2)
Resonance Testing Methods

- Family of techniques based on examining resonance behaviour of part
- High speed screening
- Especially appropriate for inspection of many nominally identical parts
- Sensitive to micro cracks but poor sensitivity to some defect types
- Almost no information on nature of defect provided
- Active area of research at MTC (Project A11481 - Triaging through NDT – NATEP funded)

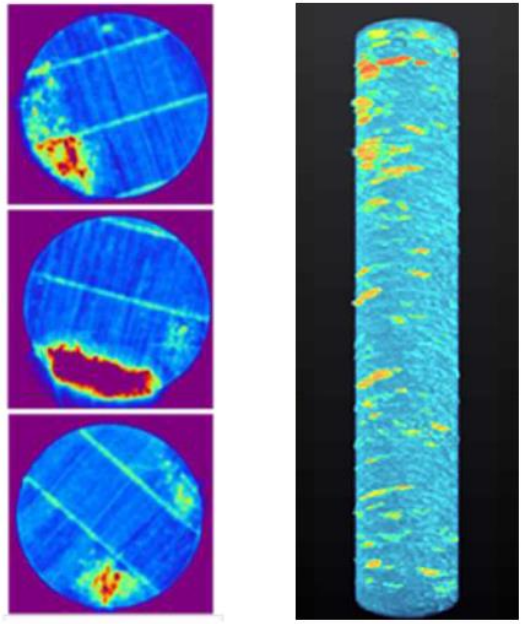


Non-linear acoustics testing showing identifiably different responses for ‘good’ and ‘bad’ AM parts

ALTERNATIVES TO XCT (3)
Elimination of / Reduction in Post-Build Inspection

- No / limited post-build inspection based on
  - Proven process stability
  - In-process monitoring
  - A screening inspection
- Highly dependent on being able to exploit data associated with AM process chain
- Active area of research at MTC

"Optical Tomography" in-process monitoring example outputs for EOS machine at MTU Aero Engines



Bamberg, Zenzinger & Ladewig, *In-Process Control of Selective Laser Melting by Quantitative Optical Tomography*, WCNDT 2016

CONCLUSIONS

- XCT is capable of inspecting many AM components
- XCT however does have multiple limitations
  - Some of these are permanent features of the technology
  - Some are being reduced / overcome through R&D
  - There is significant work left to be done!
- There are alternative approaches for the post-build inspection of AM parts that do not depend on the extensive use of XCT
  - There is significant work left to be done!
- XCT is only a partial solution for AM inspection

ACKNOWLEDGEMENTS

- Colleagues:
  - Dr Ben Dutton
  - Dr Mohd Hashimi Rosli
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- Other projects referred to:
  - Samulet II – Technology Strategy Board / Innovate UK
  - Simulation-Enhanced Inspection – Core Research Programme

- Questions?
- nick.brierley@the-mtc.org

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