Manufacturing Technology Centre

SIMULTANEOUS INTEGRITY & DIMENSIONAL CT INSPECTION

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1. BACKGROUND
1. General

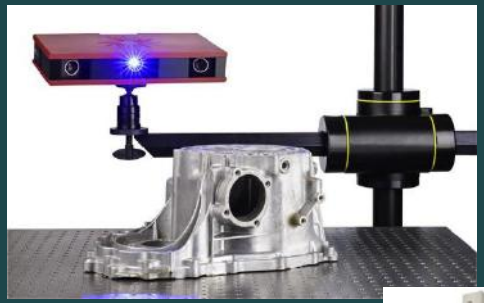
- Computed Tomography (CT) is widely used for the non-destructive inspection of AM components.
  - Insensitive to sample geometry and surface finish.
- CT is primarily used for integrity inspection / defect detection, with a separate measurement technique being applied to confirm dimensional conformance.
  - But latest CT systems can also be used for dimensional metrology, including of inaccessible features.
- The most frequent industrial concern regarding CT is the cost (/time) of CT inspections.
  - Simultaneous integrity and dimensional inspection is one possibility for addressing this.

From Zeiss brochure

1. BACKGROUND
2. Simultaneous Inspection

- Using a CT scan for both integrity & dimensional inspections
  - Potentially eliminating a separate dimensional inspection process

From Nikon brochure



From GOM.com

From hexagonmetrology.eu

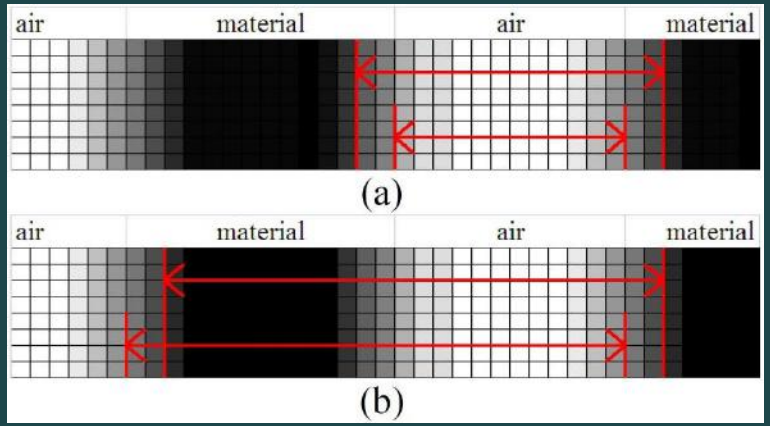
From Nikon brochure

1. BACKGROUND
3. Limitations of CT

- In the context of simultaneous inspection it is important to bear in mind the many limitations of CT.
- NDT / general limitations, including:
  - The need to rotate the part – ruling out very large parts
  - The need to penetrate the part – ruling out very thick / dense parts
- Dimensional metrology limitations, including:
  - Many sources of uncertainty, most not fully understood
  - Lack of traceability & comprehensive standards

1. BACKGROUND
3. Limitations of CT (2)

- The segmentation / surface determination in analysis of CT data has potential to substantially affect inspection performance:
  - For NDT, this relates to probability of detection & false calls
  - For dimensional metrology, edge dependent measurands will have a strong dependence



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.*

2. SIMULTANEOUS INSPECTION
1. Advantages

- Time & money savings compared to alternative based on a separate dimensional measurement process
- CT overcomes some limitations of tactile & optical sensors, e.g. regarding
  - Access to re-entrant features
  - Surface roughness
- The scanning time is independent of
  - Workpiece complexity
  - Number of features to be inspected

2. SIMULTANEOUS INSPECTION
2. Disadvantages / Limitations

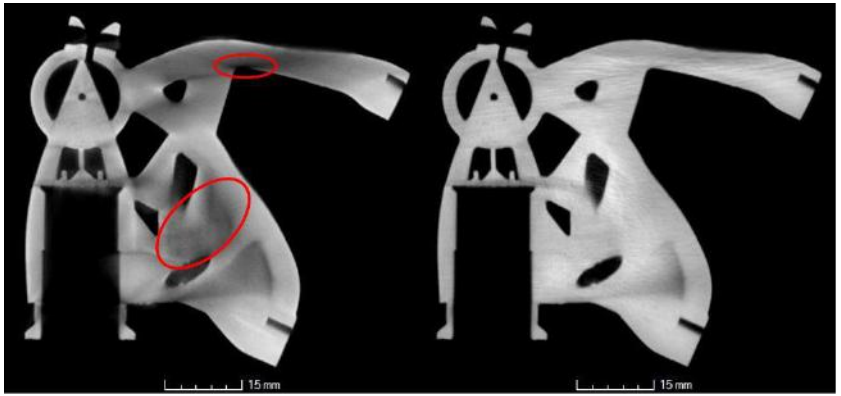
- The workpiece and associated measurands may not be suitable for dimensional measurement using CT
- Additional costs could be incurred upgrading equipment for dimensional measurement
- The manufacturing process possibly needs to be reconfigured for simultaneous inspection
- A compromise of settings (including fixture) having to be accepted, between two optimal configurations
- Potential additional costs associated with the possible collection of more data overall (given changes to CT configuration)
- A loss of flexibility & availability of dimensional metrology hardware if conventional metrology system is eliminated from the shop floor

3. INSPECTION STRATEGIES
1. Overview

- Different inspection strategies exploiting simultaneous integrity & dimensional CT inspection can be identified:
  - Using CT data in isolation
    - Separate dimensional metrology step completely eliminated
  - Using CT data together with data from a master part
    - Convectional (tactile / optical) dimensional assessment of master part
  - Using CT data together with some data from one or more conventional (tactile / optical) metrology systems
    - Limited conventional metrology data collected, either as a separate processing step or concurrently with CT scan, and exploited in data evaluation

3. INSPECTION STRATEGIES
2. CT in isolation

- Desirable financially as separate, conventional metrology step can be eliminated
- Feasible only if circumstances are favourable for using CT for dimensional measurement
  - CT can fully satisfy measurement requirements
- Features on metrology CT systems are designed to increase likelihood of system being able to satisfy requirements
  - E.g. GE's scatter|correct feature can provide improved greyscale homogeneity in presence of x-ray scattering from sample, supporting clean and accurate surface determination



Slice through conventional CT scan volume of a steel part (left) and scatter corrected scan using GE scatter|correct (right). Highlighted areas in red are subject to scatter artefacts. Scan carried out as part of a system trial at GE in Wunstorf, Germany. Sample geometry courtesy of GRM Consulting Ltd.

3. INSPECTION STRATEGIES
3. CT plus data from a master part

- Relevant only to inspection of multiple nominally identical parts
  - Serial production rather than R&D / bespoke work
- Requires one or more well-characterised good parts
  - A “virtual golden part”, a composite of several experimental datasets, can be used if no single sample can be identified
- Essentially uses CT as a comparator, or gauging system
  - Bypasses concerns relating to measurement traceability
  - Provides limited information on deviations
- Repeatability of the CT data acquisition critical
  - Periodic re-calibration of master part necessary
  - More frequent re-calibration needed if hardware not used consistently

3. INSPECTION STRATEGIES
4. CT plus conventional metrology

- Potential benefits vs. a CT-only measurement approach:
  - Tactile / optical points may take care of measurands for which CT is unsuitable, so remainder can then be assessed by CT only
  - Use of tactile / optical points as part of a calibration procedure
    - Use edge independent measurements for voxel scaling
    - Use edge-dependent measurements to initialise or fit surface determination
    - Improved traceability
  - Use of tactile / optical points to improve the CT reconstruction and hence improve the data for measurements to be extracted
    - Beam-hardening compensation from path-dependent X-ray absorption
    - Seeding of iterative reconstruction
- No off-the-shelf tools exist to facilitate all these possibilities

3. INSPECTION STRATEGIES
4. CT plus conventional metrology (2)

- Considerations when embedding a convectional measurement system into a CT enclosure:
  - Tactile: will have to occur before or after the CT scan to avoid interfering with this, incurring a time and cost penalty
  - Optical: potential interferences between X-rays and optical detection system used
  - Both: size & positioning constraints, given radiation safety must be maintained; potential long-term radiation damage to equipment

3. INSPECTION STRATEGIES
4. CT plus conventional metrology (3)

- Only commercially advertised systems that combine CT with conventional measurement technologies are Werth multi-sensor CMMs

Tactile probe in CT enclosure

http://www.werth.de/fileadmin/media/pdf/Hauszeitung/Multisensor_E_2016.pdf

CONCLUSIONS

- CT can overcome limitations of tactile & optical sensors
  - Especially regarding internal features & scanning time
- But sample & associated measurands may not be suitable for dimensional measurement using CT
  - Edge independent measurands are more likely to be suitable than edge dependent measurands
- It may be necessary to accept a compromise of settings, between optimal configuration for integrity and dimensional inspection purposes
- There are significant potential barriers to the introduction of simultaneous inspection, e.g.
  - Additional capital costs
  - Need to reconfigure the manufacturing process chain
- Possibility of supplementing CT data with limited tactile / optical data a promising option
  - High level of flexibility
  - Potential for an improvement in data quality & measurement traceability vs. a CT-only inspection
- Whilst some of latest hardware & software is geared towards enabling simultaneous inspection, there are so far no off-the-shelf solutions for exploiting all the possibilities of a CT inspection supported by limited tactile / optical measurements.

- Questions?
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