Advances in automated high throughput fan beam CT for DICONDE-conform multi-wall turbine blade wall thickness inspection and 3D additive manufactured aerospace part CT inspection

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Outline

fan beam CT inspection of multi-wall turbine blades

cone beam CT inspection in additive manufacturing

applications & solutions
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Metals Affordability Initiative - MAI
CR/DR Impl. Consortium: Member Companies

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Metals Affordability Initiative (MAI)
MAI Affordable CT Program

Technology driver:
Engine performance requirements become more stringent. High performance engines utilize cooling schemes with advanced multi-wall casting technology

Inspection problem:
State of the art measurement technologies (UT) are not capable of determining the acceptability of these new multi-wall castings

Conclusion:
The advances in turbine engine component design (multi-wall blades) drive a clear need for CT technology.

FOR GE internal use ONLY
MAI Program Objectives

Accurate and repeatable - compliance with MAI Affordable Guidelines, demonstrate measurement capability of +/- 5% or 0.001 inch

Efficient - up to 30 parts/hour (up to 10 CT slices per part)

Data integrity and security - DICOM and link to long-term image archiving solution for 2D images and slices
System Overview – External View
System Overview - Configuration

**X-ray source:**
ISOVOLT Titan 450M2/0.4-1.0HP

**Detector:**
GE "Jupiter" LDA Detector with 100 micron pixel pitch

**Manipulator:**
SCARA Robot - Adept Cobra S600 robot

**Software:**
GE Platform Architecture – acquisition, review, reconstruction and workflow
System Overview – Internal View

- IQI fixture
- Part loading fixture
- 450M2/0.4-1.0HP
- GE Jupiter LDA
- ISOVOLT Titan 450
System Overview – Cut-Aways
System Overview – Cut-Aways
Inspection Envelope

**Part Height:**
190 mm (7.48 in)

**Part Diameter:**
~150mm (5.9 in)
* Limited by detector width

**Weight:**
2.0 kg (4.40 lb) at full speed
Workflow – Wall Thickness

Start

- Load part tub 2 with max. 25 Blades outside the cabinet
- Open Sliding door manually
- Change part tub 1 with part tub 2
- Manual input of the Blade ID’s (Hand scanner)
- Close Sliding door by manually

Grip Blade n.. with Robot

X-Ray Inspection defined Positions / Blade

Load Blade n.. back to part tub
Workflow – Wall Measurement
Workflow – 2D with Spot Check CT

Start

Load part tub 2 with max. 25 Blades outside the cabinet

Open Sliding door manually

Change part tub 1 with part tub 2

Manual input of the Blade ID’s (Hand scanner)

Close Sliding door by manually

Load Blade n.. back to part tub

X-Ray Inspection defined Positions / Blade

Grip Blade n.. with Robot

X-Ray Inspection defined Positions / Blade

Grip Blade n.. with Robot

Load Blade n.. back to part tub

Define optional CT slice measurements with Rhythm

Optional
Used fan beam calibration artifact described in MAI guidelines document. 3 cylindrical holes of 8, 10, 12 mm diameter.

Process:
CT scan at given vertical position
Measure circle diameters, distances between circles. Correspond to probing error size and length measurement error.

Compare results to DKD (NIST equiv.) calibration report, CMM measurements.

Apply correction factor to system if necessary.
## System Capabilities - Preliminary

### Preliminary System Results
- Length measurement error $< 5\, \mu m$
- Probing error $< 2\, \mu m$
- Total error $< 7\, \mu m$

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<th>Measured (mm)</th>
<th>Nominal (mm)</th>
<th>Difference (mm)</th>
<th>Distance measured (mm)</th>
<th>Nominal (mm)</th>
<th>Difference (mm)</th>
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</table>

- Probing error size $0.0019$
- Length measurement error $0.0047$

Sum probing error plus length measurement error $0.0066\, mm$

- Temperature
  - 12:22pm $24.6C$
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Excursus: CT for Additive Manufacturing

Utilized principle: SLS – selective laser sintering

Used manufacturing device:

Sources: Wikipedia, Concept Laser
Additive Manufacturing – example for CT analysis

Product:
Additive manufactured workpiece

Material:
TiAl6V4

Dim (LxWxH):
100x55x30 mm
Additive Manufacturing – example for CT analysis

Inspection Task:
- Defect analysis
  - Porosities,
  - Inclusions,
  - Cavities
- Dimensional analysis
  - Wall thickness,
  - CAD comparison

By courtesy of
Additive Manufacturing – example for CT analysis

U = 260 kV
I = 550 µA
Vx = 100 µm
F: 1 mm Sn
Used µCT system: v|tome|x m 300
Additive Manufacturing – example for CT analysis

3D image: rendered surface

Used μCT system:
v|tome|x m 300

By courtesy of AEROTEC
Additive Manufacturing – example for CT analysis

2D slices and 3D image

Used µCT system: v|tome|x m 300

By courtesy of
Additive Manufacturing – example for CT analysis

3D image: porosity analysis

Used μCT system: vтоме|x m 300
Additive Manufacturing – example for CT analysis

3D image:
wall thickness analysis

Used µCT system:
v|tome|x m 300
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applications & solutions
Aerospace X-ray applications

Turbine & compressor blades / airfoils

Typical X-ray inspection results
Aerospace X-ray applications

Investment castings / structural castings / nozzles

Typical X-ray inspection results
Aerospace X-ray applications

CFRP/GFRP composites & fan blades / Ceramic Matrix Comp.

Typical X-ray inspection results
Applications & solutions
Increasing X-ray inspection requirements driving change

Technology Introduction

Film

X-ray Tubes

CR

Digital Systems

Advanced Digital

Computed Tomography Assisted Defect Recognition

Broad Acceptance Industry Standards
DICONDE: Standardization of digital X-ray Imaging

Add any DICONDE device into your network and it will communicate with your other DICONDE systems.
Outlook

move from classical to digital radiography on short/mid term - > DICONDE standardization + data handling & storage forward

innovative aerospace manufacturing technologies - > different kinds of defects require increased detectability

continuous challenges in terms of productivity, resolution for X-ray manufacturers - > NPI/NTI drivers

..special acknowledgement to
Thank you very much for your kind attention!

..any questions?