Numerical Simulation of Additively Manufactured Metal Component

12th International Symposium on NDT in Aerospace
Williamsburg, VA, USA
October 2020

STUDENT CHALLENGE

ND - Taskforce

Prof. Kazimieras Barsauskas Ultrasound Research Institute
Kaunas University of Technology
Lithuania
Flaws in the Jet Engine Turbine Blade

- Spherical volumes of trapped powder (50 μm-3 mm)
- 2D and 3D arrays of trapped powder
- Complex helical volumes of trapped powder
- Simulated cracks between airfoil & blade root
- Large enclosed volumes
- Trapped powder resolution grids
- Large prismatic trapped powder volumes (20mm)

Material:
Blade: Ti-6Al-4V
Defects: air/void
Aim
To identify defects and to propose most suitable technique for the inspections of additively manufactured components

Objectives
• Selection of suitable NDT techniques
• Tools and optimal parameters
• To set the benchmark NDT methods for inspection of various defects size (50 μm – 20 mm)
Numerical Simulation

• Radiography testing
  • Inspection of Aerofoil
  • Inspection of Dovetail

• Ultrasound technique
  • Inspection of dovetail on jet engine turbine blade
    • Beam computations with single element contact and immersion
    • Inspection simulation using contact single element
    • Immersion technique
  • Inspection of Aerofoil on jet engine turbine blade
    • Beam Computation
    • Inspection of SDH with Contact and Immersion Technique
    • Contact and immersion test on top of the blade
    • Inspection of Spherical holes
Problems in inspecting additively manufactured components

- High attenuation due to grainy structure.
- Ultrasonic wave scattering leads to mask the small flaws.
- Planar cracks with length that lie parallel to the direction of ultrasonic wave travel are not detectable.
Defects in the Dovetail of the blade

- 1 Pyramid
- 2 Star
- 3 Helical spheres
- 4 Rectangle plate
- 5 Rods from airfoil
- 6 Varying thickness inclusions
- 7 Slot
- 8 Foreign object
- 9 NASA text logos
- 10 Two - side drill holes
- 11 Circle
- 12 Group of plates
Defects in the Airfoil of the blade

- 7 Spheres
- 8 Crack from hole
- 9 Coil
- 10 Slot
- 11 Curved plate inclusions
- 12 NASA logo with holes and stars
- 13 Rods to dovetail
- 14 rods
- 1-6
Radiography Inspection
Source Specification

X-Ray

• Intensity current – 1mA
• Acceleration voltage – 450V
• Radius – 1.5mm
• Opening angle – 22 deg

Gamma

• Source intensity – 2000 GBq (Becquerel of radioactivity)
• Radius – 1.5mm
• Opening angle – 22 deg
• Height – 3 mm

HE

• Dose rate – 1GY/min (Gray Unit/min)
• Radius – 1.5mm
• Opening angle – 22 deg
Detector and scanning specification

- Pixel size – 0.1mm
- Resolution – 1600x1200 pixels
- Source to Object (SOD) – 690 mm
- Object to Image (OID) – 85 mm
- Exposure time – 4s
X-Ray Result – Angle 0°

Photon beam penetration
X-Ray Result – Angle 30°

Photon beam penetration
X-Ray Result – x rotation 90°
X-Ray  
Gamma  
High Energy
X-Ray Result – Angle 0°

Photon beam penetration

Two side drill holes
X-Ray Result – Angle 30°

Photon beam penetration

Rods from Airfoil

Two side drill holes
X-Ray Result – Angle 90°

Photon beam penetration

Two side drill holes different sizes
Ultrasonic Inspection – Whole sample
Ultrasonic Inspection – Whole sample
Dovetail – Beam inspection

\[ f = 5 \text{ MHz} \]

\[ f = 7.5 \text{ MHz} \]

\[ f = 15 \text{ MHz} \]

\[ f = 20 \text{ MHz} \]
Dovetail - Contact inspection

- **Wave type** – Shear wave
- **Probe type** – Single element w/wo wedge
- **Probe shape** – Circle
- **Probe diameter** – 5 mm
- **Wedge material** – Plexiglass
- **Wedge angle** – 54°
- **Frequency** – 7.5 MHz
- **Wavelength shear** – 0.4 mm
- **Mesh size** – 0.001 mm
Dovetail – Contact result
Dovetail - Immersion technique

- **Wave type** – Longitudinal wave
- **Probe type** – Single element immersed
- **Probe shape** – Circle
- **Probe diameter** – 5mm
- **Incidence angle** – 26°
- **Frequency** – 7.5 MHz
- **Wavelength longitudinal** – 0.8 mm
- **Wavelength shear** – 0.4 mm
- **Mesh size** – 0.001 mm
- **Water path** – 14 mm
Dovetail - Immersion result
Airfoil – Immersion technique

- **Wave type** – Longitudinal wave
- **Probe type** – Single element immersed
- **Incidence angle** – 0°
- **Frequency** – 7.5 MHz
Immersion inspection on rear side of airfoil

- **Wave type** – Longitudinal wave
- **Probe type** – Single element immersed
- **Incidence angle** – 0°
- **Frequency** – 7.5 MHz
Airfoil leading edge

- **Wave type** – Longitudinal wave
- **Probe type** – Single element immersed
- **Incidence angle** – 0°
- **Frequency** – 7.5 MHz
Calibration results in scanning path 1 with contact and immersion techniques
Calibration

Contact

Immersion
Ultrasonic Inspection – particular defects in airfoil side of the blade
Content

• Inspection of Aerofoil on jet engine turbine blade
  • Beam Computation
  • Inspection of SDH with Contact and Immersion testing
  • Inspection of FBH with Contact and immersion testing
  • Inspection of Spherical holes using contact and immersion testing
Contact inspection – Phased array

- Wave type – Shear wave
- Probe type – Phased array (16 elements)
- Wedge angle – 35°
- Focused type – Multi-focusing
- Frequency – 10 MHz
- Wavelength – 0.3 mm
- Mesh size – 0.01 mm
Phased array - Beam computation
Immersion technique – Beam computation

- **Wave type** – Longitudinal wave
- **Probe type** – Single element
- **Focused type** – Flat
- **Transducer type**: GE-0069141-MWB2PA16 from CIVA library

- **Frequency** – 20 MHz
- **Wavelength** – 0.3 mm
- **Mesh size** – 0.01 mm
Contact and immersion inspection

**Phased array transducer**

- **Central frequency:** 10 MHz
- **Wave type:** Shear wave
- **Tools:** Contact phased array transducer

**Flat Bottom Holes (FBH)**
- 2 mm
- 0.5 mm

**Single element transducer**

- **Central frequency:** 20 MHz
- **Wave type:** Longitudinal wave
- **Tools:** Single-element flat transducer

**Star shape CAD-Planar films**
Contact and immersion inspection result
Inspection of SDH with Contact and Immersion Technique

- Linear phased array
- SDH-1
- SDH-2: Jet engine blade
- SDH-3

Central frequency: 10 MHz
Shear wave for inspection
Contact phased array transducer

Dovetail

Water path
SDH-1
Single element probe

Central frequency: 20 MHz
Longitudinal wave for inspection
Single-element flat transducer
Inspection of SDH with Contact and Immersion Technique - Result

SDH location - 1
Inspection of SDH with Contact and Immersion Technique - Result

SDH location - 2
Inspection of SDH with Contact and Immersion Technique - Result

SDH location - 3
Calibration

SDH location - 1

Side Drilled Holes (SDH)
Inspection of Spherical holes

Central frequency: 10 MHz
Shear wave for inspection
Contact phased array transducer

Central frequency: 20 MHz
Longitudinal wave for inspection
Single-element flat transducer
Inspection of Spherical holes - Result
Calibration
Sensitivity analysis

(a) Sensitivity in %

- Shear wave velocity: 0.88%
- Incidence angle: 9.37%
- Frequency: 87.92%
- Flaw (0.8-2 mm): 1.05%
- Flaw (0.5-2 mm): 0.78%

(b) Uncertainty in %

- Shear wave velocity: 17.5%
- Incidence angle: 14.4%
- Frequency: 7.6%
- Flaw (0.8-2 mm): 18.8%
- Flaw (0.5-2 mm): 26.2%
## Comparison of NDT techniques

<table>
<thead>
<tr>
<th>Defect location</th>
<th>Defect Type</th>
<th>Radiography</th>
<th>Contact UT</th>
<th>Immersion UT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dovetail</td>
<td>1-11 (leading edge, Spherical pores, hole and crack)</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>12 (NASA logo with stars)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>13,14 (rods)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Airfoil</td>
<td>10 (SDH)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>1-9,11,12</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Conclusions

• In this study, radiography and ultrasonic inspection techniques were used to inspect the jet turbine blade model using CIVA in order to identify a variety of defects.

• Using radiography technique, it was possible to identify the defects in airfoil side of the blade with good contrast but not in the dovetail part due to the high thickness.

• Using ultrasonic technique,
  • The whole component was inspected and most of the defects were identified
  • Then specific defects were inspected for obtaining detailed information. It was found that with specific configuration of the transducers, all the defects can be identified.
Recommendation

• Due to feasibility and ability to inspect the structure in-situ, contact inspection is recommended because no specialized setup necessary

• Inspection using immersion technique is recommended only when high resolution of the defect is required. Also, the inspection with immersion technique can be made with one type of transducer on the complex object.

• With radiography technique, most of the defects in the airfoil side of the defect was identified but it would be difficult in the dovetail part due to the large thickness and losses due to scattering.
Thank You For Your Attention