Bionic Aircraft

Innovative in-process and in-line quality assurance systems for additive layer manufacturing

Suela Ruffa, Silvan Meile

Hexagon Manufacturing Intelligence, Hexagon Technology Center

8th EASN-CEAS International Workshop on Manufacturing for Growth & Innovation

4-7 September 2018, Glasgow, UK
HEXAGON MANUFACTURING INTELLIGENCE – 2017

- **North America**: 26% Sales
- **Central and South America**: 1% Sales
- **EMEA**: 34% Sales
- **Asia Pacific (except China)**: 11% Sales
- **China**: 28% Sales

- **1500+ SW developers and engineers**
- **500,000+ Software Licenses Installed**
- **9% of net sales invested in R&D**
- **Reached €1.3bn+ sales in 2018**
- **7,000+ employees**

- Customer service and demo centres
- Production facilities
Quality throughout the Product Lifecycle

DIGITAL WORLD

Design & Engineering Software

Production Software

Metrology Software

Data Management and Analytics

Metrology Hardware

REAL WORLD

Supply Chain

Manufacturing

Service Life

Hexagon Technology Center (HTC)

Hexagon Metrology Torino
Role of Quality Inspection into Bionic Aircraft Project

Developed systems for In-Line Inspection and results achieved

Developed systems for In-Process Inspection and results achieved

Conclusions and future works in the project
Main Goals within the Project

- Development of system for **in-process** integrity measurement on the ALM test rig
- Development of system for **in-line** integrity measurement of ALM parts (geometrical control and internal defect detection)
Activities within the Project

Paper research on 12 sensor technologies

Practical investigation on six sensor concepts

Build up functional models

<table>
<thead>
<tr>
<th>Type of integrity check</th>
<th>Sensor technology</th>
<th>Defect/Requirement</th>
<th>Geometry</th>
<th>Curing scheme</th>
<th>Repair</th>
<th>Pre-treatment</th>
<th>Heat input</th>
<th>Time</th>
<th>Accuracy</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-line</td>
<td>Laser ultrasonic</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In-line</td>
<td>Eddy current</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In-line</td>
<td>Cig</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In-line</td>
<td>Laser ultrasonic</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In-line</td>
<td>Eddy current</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In-line</td>
<td>Thermography</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In-line</td>
<td>Eddy current</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In-line</td>
<td>Capacitive sensors</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In-line</td>
<td>Ultrasonic</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In-line</td>
<td>Structural light 3D scanning</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In-line</td>
<td>Non-destructive testing</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

In-line
- Benchmark surface scanning solutions
- Resonance testing
- Ultra sonic inspection
- Eddy current
- Structured light 3D scanning
- Lead Hex-Met
- Lead HTC

In-process
In-line geometrical control: Surface Scanning

Goal and Challenges
- Geometrical inspection of ALM parts
- Challenges:
  - Geometrical complexity
  - Free-form surfaces
  - Automation of control

Preliminary Results
- Measured ALM parts with Tactile Probe and Structured Light Sensor
  Accuracy of tactile measurement is necessary for functional elements while the non-contact systems are good enough for all the other features
  - Deep analysis of the influence of different factors on the measurement results (Alignment Type, Rotary Table Calibration, Workpiece Distance, Sensor Tilt, Roughness, Shutter Time)
  Guidelines to measure an ALM part

Functional Model
- The structured light sensor was mounted on a 3 axes coordinate measuring machine equipped with a continuous wrist
In Line Surface Scanning: Developed Functional Model

- The structured light sensor was mounted on a 3 axes coordinate measuring machine equipped with a continuous wrist.
- Machine is placed in production environment with temperature, light and vibrations that cannot be controlled.
- The sensor can be rotated along an axis perpendicular to the camera focal one, rotary table is used only to rotate the part along the vertical axis.
In-Line Surface Scanning: Results

- Complete analysis of the performance of the Structured light sensor in measuring ALM parts provided the best set of parameters to be used to measure such a part.

- Complete analysis of the results on the integrated system to check the influence of different measurement parameters.

- The structured light sensor can be integrated on the CMM and preliminary results were obtained with some indications on how to improve the next version of the system.

- Machine should be placed in a stable environment (to reduce the variability).

- The method to align different scans is an important factor.

- Frequent sensor calibration is suggested in order to improve the accuracy (changes of environment conditions).
In-Line internal defect detection: Ultrasonic Inspection

**Goal and Challenges**

- Automated ultra sonic internal defect detection for complex ALM parts
- Freeform Surfaces scan
- Small defects detection

**Preliminary Results**

- Comparison of different ultrasonic sensors
- Ultrasonic is feasible for detecting common ALM defects on simple geometries (flat surfaces)
- Selection of one system (Olympus EPOCH 650)

**Functional Model**

- Integration of an Ultrasonic system flaw detector (Olympus EPOCH 650) on a coordinate measuring machine

**Table:**

| Type of defect | Dimension | Detection
|---------------|-----------|----------
| Flat surface  | YES       | YES      |
| 1.0 mm        | YES       | YES      |
| 1.5 mm        | YES       | YES      |
| 3.0 mm        | YES       | YES      |
| 4.0 mm        | YES       | YES      |
| 6.0 mm        | YES       | YES      |
| 8.0 mm        | YES       | YES      |
| 10.0 mm       | YES       | YES      |
| 20.0 mm       | YES       | YES      |
| 50.0 mm       | YES       | YES      |

**Notes:**

-この技術の利用により、特定の欠陥を検出することができる。
-このシステムは、複雑な形状をスキャンする能力を示す。
In-Line Ultrasonic Inspection

ULTRASONIC FLAW DETECTOR

SAMPLE ALIGNMENT

3D-CAD SOFTWARE

SAMPLE COORDINATES IN CMM WORKING VOLUME

CALIBRATION AND SETTING PARAMETERS

CMM MEASURING SOFTWARE

ULTRASONIC SCAN

ANALYSIS OF DETECTED DEFECTS

SCAN PATH COORDINATES
In-Line Ultrasonic Inspection: Results

**ULTRASONIC SCANNING SYSTEM**

<table>
<thead>
<tr>
<th>Component</th>
<th>Defect</th>
<th>Automatic Scan</th>
<th>Manually Scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate A1</td>
<td>Pores d=2 mm</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>Pores d=1 mm</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Plate B1</td>
<td>Pores d=0.5 mm</td>
<td>YES</td>
<td>YES (difficult interpretation)</td>
</tr>
<tr>
<td></td>
<td>Pores d=0.2 mm</td>
<td>YES</td>
<td>YES (difficult interpretation)</td>
</tr>
<tr>
<td>Plate C1</td>
<td>Delamination, thickness 0.2 mm</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>Delamination, thickness 0.05 mm</td>
<td>NO (not sure about the presence)</td>
<td>NO (not sure about the presence)</td>
</tr>
<tr>
<td>Plate D1</td>
<td>Delamination, thickness 0.2 mm</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>Delamination, thickness 0.15 mm</td>
<td>YES</td>
<td>YES (difficult interpretation)</td>
</tr>
<tr>
<td></td>
<td>Delamination, thickness 0.2 mm, surface area 5 x 5 mm²</td>
<td>YES</td>
<td>YES (difficult interpretation)</td>
</tr>
<tr>
<td></td>
<td>Delamination, thickness 0.2 mm, surface area 10 x 10 mm²</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>Pore d= 1 mm, empty bracket</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>Pore d= 0.7 mm, empty bracket</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>Pore d= 0.5 mm, empty bracket</td>
<td>YES</td>
<td>YES (difficult interpretation)</td>
</tr>
<tr>
<td></td>
<td>Pore d= 0.3 mm, empty bracket</td>
<td>NO (difficult interpretation)</td>
<td>NO (difficult interpretation)</td>
</tr>
<tr>
<td></td>
<td>Pore d= 1 mm, full bracket</td>
<td>NO (inaccessible area)</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td>Pore d= 0.5 mm, full bracket</td>
<td>YES</td>
<td>YES (difficult interpretation)</td>
</tr>
<tr>
<td></td>
<td>Pore d= 0.3 mm, full bracket</td>
<td>YES</td>
<td>YES (difficult interpretation)</td>
</tr>
</tbody>
</table>
In-Line Ultrasonic Inspection Future Works

- Improvement of the mechanical and electrical interface between ultrasonic transducer and Wrist/CMM
- Testing and tuning of the automatic system for application of the coupling gel
- Testing on bionic parts different than the “Bamboo Bracket”
- Improvement of ultrasonic signal analysis in order to obtain the dimensions of the detected defects
- Improvement of the measuring SW
In-process quality control – Structured light 3d tech.

**Working principle**

1. Calibration
2. Fringe Projection
3. Image Acquisition
4. Image Analysis
5. Stereo Matching
6. 3D Reconstruction
In-process quality control – Structured light 3d tech.  
Integration on ALM Test Rig
**In-process quality control – Structured light 3d tech.**  
*Metrological performance*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral Resolution (x-y Plane)</td>
<td>50 um</td>
</tr>
<tr>
<td>Depth resolution (z-direction)</td>
<td>5 um</td>
</tr>
<tr>
<td>Lateral accuracy</td>
<td>10 um</td>
</tr>
<tr>
<td>Temperature influence</td>
<td>System is constantly calibrating itself during a build job</td>
</tr>
<tr>
<td>Measurement time</td>
<td>6 s</td>
</tr>
</tbody>
</table>
In-process quality control – Structured light 3d tech.

Use cases

- Measurement of melted area
- 3D-Measurement on the fly (stack the measurements of melted area)
- Measurement of deposited layer thickness
- Additional information from a full scan (ALM expert..)?
Conclusions and future works

- Functional models were developed for both in-line and in-process integrity system
- Some issues were detected and possible solutions/improvements are already designed and will be developed
- Further tests are planned for the last year of the project
Thank you for your attention!

- **Suela Ruffa**  
  Hexagon Manufacturing Intelligence  
  10095 Grugliasco-Torino (Italy)  
  suela.ruffa@hexagon.com

- **Silvan Meile**  
  Hexagon Technology Center GmbH  
  9435 Heebrugg (Switzerland)  
  silvan.meile@hexagon.com

This project has received funding under the European Union’s Horizon 2020 research and innovation programme under grant agreement No 690689.