Quantitative 3D Evaluation of Defects in CFRP Materials using active Lock-in Thermography

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Department for Model-based Systems – Introduction
Production Engineering at RWTH Aachen University

**Machine Tools Laboratory (WZL)**
- Institute of the RWTH Aachen
- established in 1906
- about 840 employees
  (about 250 research assistants)
- 10 000 m² office and laboratory area

**Fraunhofer Institute of Production-Technology (IPT)**
- Institute of the Fraunhofer-Corporation
- established in 1980
- about 450 employees
  (about 124 research assistants)
- 3 000 m² office and laboratory area
- Associate-Institute in Boston/USA: CMI
  Fraunhofer Center for Manufacturing Innovation

**WZL Forum**
- Offers further educational measures and workshops (e.g. Executive MBA)
Chair of Metrology and Quality Management
Department for Model-Based Systems

Mobile Coordinate and Machine Vision Systems
Laser interferometry, computer vision, thermography, photogrammetry, computed tomography, ultrasonic

Metrology Assisted Assembly
Robotics, sensor technology, location/positioning systems, process and capability analysis, industrial statistics

- Precision metrology in large volumes
- Metrology enabler for machine tools
- Structure monitoring under thermal conditions
- Computer vision applications
- Quality assurance for the FRP process chain

- Fixtureless assembly
- Assembly in motion
- Changeable assembly system design and planning
- Process evaluation
- Confidence- and capability proofing

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Introduction
Fiber Reinforced Plastics – Quality Assurance

Quality assurance of fiber reinforces plastics vary from different use cases. Metrology and testing technologies are key to ensure quality standards for customer acceptance and safety.
Chair of Metrology and Quality Management
Quality Assurance along the FRP Process Chain

Semi-finished production process
Preforming
Finishing processes
Trimming, joining
Repair

Quality assurance

Optical sensor systems
X-ray sensor
Sensor-assisted handling
Ultrasonic system
Thermography system

Defect detection
Area density
Fiber orientation
Digitization
Testing of adhesive bonds
Impact detection
Delamination and inner folds
Sensor Technology
Functional Principle Active Lock-in Thermography

- Part excitation with sinusoidal heat excitation with halogen spot lights
- Change of heat transfer due to inhomogeneities (e.g. defects)
- Recording of change of IR radiation on the part surface with IR camera
- Data processing and information representation as phase image (Fourier transformation)
Non-Destructive Impact Damage Detection on Carbon Fiber Reinforced Plastics

Prof. Dr.-Ing. Robert Schmitt
WZL RWTH Aachen
Prof. Dr. Eng. Armando Albertazzi Gonçalves Jr.
LABMETRO / EMC / UFSC
Non-Destructive Impact Damage Detection on Carbon Fiber Reinforced Plastics (IDD-Metro)

**Motivation**
- CFRP component repair condition must be assured without affecting the operational reliability.
- Need for a non-destructive, reliable, efficient, automated measurement technology to fit the material, component and repair shop floor specific requirements

**Goals**
- Qualification of thermography to reliably detect damages with their respective 3D properties (size, shape, position and depth) in CFRP components
- Development of a virtual model of the component’s defect
- Enabling a reliable repair process in the workshop environment
- Next step: Extension of the model to other materials and defects
IDD-Metro
Project Proposal

Component Analysis
- materials
- geometries
- impact damages
1st Phase (2014-2016)

Sample Preparation
- structuring
- experiments
- design of experiments (DoE)

Thermography
- parameters optimization
- images dimensioning
- tests and validation

Computed Tomography
- parameters definition
- optimal volumetric matrix
- tests and validation

Defects Attributes
- identification
- structuring
- data model

2nd Phase (2016-2018)

Defects Modelling
Data Fusion
Multisensor Solution
- 3D digitalization
- thermography
- data fusion
- validation
IDD-Metro: Procedure
Determination of the Defect Geometry in CFRP Samples

1. Manufacturing of blind bore hole samples
2. Examination with thermography
3. Analysis and mathematical description of the deviation
4. Calculation of the defect's geometry based on thermography data
5. Transfer to internal defects
6. Reference measurement with computed tomography
7. Calculation of the correlation between thermography and CT data

CMM reference measurement

\[ y = 8.333n(x) + 73.864 \]
\[ R^2 = 0.8944 \]
IDD-Metro: Investigations and Findings
CT Measurement Results and Comparison with Thermography

- Development of a software program for automated defect detection in CFRP parts
- Analysis of the different setting parameters on the thermography measurement results and determination of the optimal measurement set-up
- Calculation of the deviation between thermography and CMM measurement results and
- Development of a defect model based the thermography data
- **Outlook:** Referencing thermography measurements of damaged test samples with CT.
Motivation

- Structural CFRP car components require a new and reliable repair and maintenance concept due to their specific material demands
- To enable the application of CFRP in automotive serial production existing repair shops need to be equipped for this new challenges

Tasks

- Development of testing processes for reliable defect detection in repair shops
- Standardized defect detection
- Repair concepts for different defect types
- Equipment of repair shops (interactive assistant systems)
- Detailed business model
CFK-Werkstatt
Approach of the Research Project

„Interactive Repair Shops for Future CFRP-Electric Cars“
## Comparison: Ultrasonic testing and Lockin-thermography

<table>
<thead>
<tr>
<th></th>
<th>Ultrasonic testing</th>
<th>Lock-in thermography testing</th>
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</thead>
<tbody>
<tr>
<td>Axial resolution</td>
<td>● ● ● ● ○</td>
<td>● ● ○ ○ ○ ○ ○ ○</td>
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<td>Lateral resolution</td>
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<td>Testing range</td>
<td>● ● ○ ○ ○</td>
<td>● ● ● ● ● ● ●</td>
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<tr>
<td>Testing speed</td>
<td>● ● ● ● ○</td>
<td>● ● ● ● ● ○ ○</td>
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<tr>
<td>Penetration depth</td>
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<td>● ● ● ○ ○ ○ ○</td>
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- Thermography suited for a fast, extensive near surface defect detection
- Ultrasonics most suitable for a high-resolution defect classification even in deeper layers

**Conclusion:**
1.) Fast large area thermography scan for ROI determination
2.) Ultrasonic scan of the ROI for defect detection and classification
3.) Fusion of NDT data sets
NDT Data Fusion: General Approach

1. Generation of multiple NDT data sets
2. 3D damage detection and visualization
3. Registration of damage data in the same coordinate system
4. Fusion of damage data and classification

Damage information:
- size, shape
- position, orientation

Source: olympus-ims.com, flir.de
Summary and Cooperation Potential

Summary

- The WZL provides quality assurance in FRP-Production
- Lock-in thermography enables automated defect detection and classification
- Concept of sensor data fusion combines the advantages of ultrasound and thermography for challenging inspection tasks

Cooperation potential

- Development of testing concepts and their implementation
- Development of customized software solutions for automated defect detection and classification
- Integration of measurement systems as quality control loop and for inline quality assurance
- FRP service measurements with different sensor systems
Thank you for your attention!