Aircraft maintenance in the CFRP future
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Maintenance for CFRP parts - The considered process chain

SHM (Lamb Waves) -> NDT (CT improved US) -> Repair (RPR) -> Bondline Control

This repair is ok
Maintenance for CFRP parts – The Challenges

- Barely visible damages
- Integral structure with hidden elements
- Enhanced thresholds

Defect Types to be detected:
- Delamination
- Delamination on Insert
- Impact
- Crack
- Core crush
- Heat damage
- Disbond

Vision: Structure with self-sensing capability

Delamination in US Impact with Core Crush
SHM with Guided Lamb Waves – The Vision

- Fast testing of structure integrity by acoustic ultrasonic waves (lamb waves)
- Structure integrated observation network in damage prone areas, locations difficult to inspect, inaccessible areas
- Efficient off-board monitoring to localize potential deviations / defects
- Light and intelligent sender/receiver elements, connected by structure integrated low voltage / low power wiring

Inaccessible Area: Sandwich Structure
Damage Prone Area: Door Surround Structure
SHM with Guided Lamb Waves – Technology (I)

Working Principles

Guided waves can penetrate large areas and interact with defects.
Their excitation and reception is possible with piezoceramic (PZT) patches

- No time consuming scanning required
- Inspection of complex components
- Evaluation of time of flight, amplitude and wave types

However:
- For each frequency at least two different wave modes exist
- Each mode is dispersive
- Interaction between Lamb-waves and damage is complex and difficult to predict
- A practical application requires a high degree of research and development

CFRP-component with PZT-patches used as actuators and sensors for Lamb-waves
SHM with Guided Lamb Waves – Technology (II)

Working Principles

Received signal going through intact structure

Received signal through structure with local defect
SHM with Guided Lamb Waves – Technology (III)

Capturing of 3D-Lamb Wave Data Files

- Excitation of a fixed PZT
- Meander scanning, grid 2x2 mm
- Excitation at each point of the scanning grid
- Air-coupled scanning receiver
- 3D-data file (x-y-t), file size 1-20 Gbyte
- Scanning time: for 600*800 mm:
  - 40 min.(240,000 points)
- Comparison: scanning laser doppler vibrometer (SLDV) 300 points within 20 minutes

\[ A = f(x, y, t) \]
Lamb Wave Mode Selection to Filter Required Information

- At a given frequency there exist a series of wave modes
  - Symmetric modes (S<sub>n</sub>-tension-modes)
  - Antimetric modes (A<sub>n</sub>-bending-modes)
- Each mode has its specific speed and wavelength
- Below a material specific frequency (f<sub>g</sub>) only A<sub>0</sub>- and S<sub>0</sub>-mode are generated
SHM with Guided Lamb Waves – Technology (V)

Wave Reflection Due to Distortion Leads to Mode Conversion

Example:
Local area on a tailboom has been analyzed with stiffness change on skin due to bonded additional sensor.

Actuator sends a single mode.

The reflected mode shows a different wavelength.

The distortion (stiffness) leads to mode conversion.

EC135 Tailboom (AISHA II Project)
SHM with Guided Lamb Waves – Remaining To Do’s

- Algorithms for signal analysis to localize deviations
- Correlation between signal analysis and size of defect
- Range of applicability to be evaluated
- Technology required to assess optimal actuator/sensor placement for specific structures
- Self diagnosis capability
- Proof of reliability / durability in operational tests
- Technology Certification
NDT with Computer Tomographie – Method

Basics

X-ray Source  Sample  Detector

Step-by-Step Rotation

X-ray

Tube Control  CNC object stage  Data Acquisition

Computed Tomography / Volume Reconstruction
NDT with Computer Tomography – Method

Devices

Mikrofocus
Resolution 5 µm (240 KV)

Nanofocus
Resolution 2 µm (160 KV)
NDT with Computer Tomography – Process

The Potentials

Resin and embedded glass fibers

Digital extraction of glass fibers
NDT with Computer Tomographie – Method

Analysis of Complex Structures

Advantages
- 3D-image of damage area
- Digital separation of impactor without influencing the impact area
- Quantitative analysis of defects

Limits
- Limited size of inspectable parts depending on resolution

Double-wall structures (CFRP)
NDT with Computer Tomographie – Method
Bridging the mobile NDT methods

From 2D-Information to 3D-Information

Air-coupled ultrasonic

Computer-tomography

Improved interpretation of effects of defects
NDT with Computer Tomographie – Method

Bridging analysis and FEM

- CT-Analysis of defects
- Meshing of defect area
- FEM based calculation of remaining mechanical performance
CFRP Repair – Major Challenges

Challenges

- Reduction of Maintenance Time
- Reduction of Maintenance Costs
- Quality
- Reproducibility / Human Factor
- Performance

Solution

- Automation of Repair Process

Repairs done tomorrow
Demonstration of B787 Repair
CFRP Repair – Integrated Process Chain

Phases

1. Identification and Localization of Damage
2. Scanning of real Geometry
3. Choice of suitable Repair (Geometry / Layup / Material)
   - Automated Milling / Grinding of Taper and Repairhole
4. Scanning of Repair Position and Patch (As-Is versus To-Be)
   - Manufacturing of suitable Tooling via Rapid-Prototyping
   - Manufacturing of suitable Patches
   - Automated Positioning and Bonding of Patches
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Choice of suitable Repair (Geometry / Layup / Material)

Automated Milling / Grinding of Taper and Repairhole

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Manufacturing of suitable Tooling via Rapid-Prototyping

Manufacturing of suitable Patches

Automated Positioning and Bonding of Patches
CFRP Repair – Integrated Process Chain

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2. Scanning of real Geometry
3. Choice of suitable Repair (Geometry / Layup / Material)
4. Automated Cleaning / Milling / Grinding of Taper and Repairhole
5. Scanning of Repair Position and Patch (As-Is versus To-Be)
6. Manufacturing of suitable Tooling via Rapid-Prototyping
7. Manufacturing of suitable Patches
8. Automated Positioning and Bonding of Patches

Source: IFS TU Braunschweig
CFRP Repair – Integrated Process Chain

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Quelle: Fa. EOS
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CFRP Repair – Removing the Damage

- Preparation of Damaged Area for Bonded Repair
  - Alignment of 3D-data
    - Preparation of Damaged Area for Bonded Repair
    - Focussing of 3D data on relevant region
    - Reduction of 3D-data density
    - Triangulation of 3D-point cloud
    - Reconstruction of real geometry
    - Checking of deviation
    - Design of tapered repair based on real 3D-shape
  - Damage removal by milling of structure
  - Structure prepared for patchrepair
  - Process demonstrated on unstiffened panel
  - Automated positioning and bonding of repair patches

Cross section of cured prepreg, cutted with different milling methods. © Laser Zentrum Hannover (LZH)
CFRP Repair – Repair of Tomorrow

Combination of Repair Modules in one Unit for automation
CFRP Repair – Repair of Tomorrow
Combination of repair modules in one unit for automation

Tasks of today’s robots

Hanging lazy beside a door...

Tasks of tomorrow’s robots?

Actively searching defects and repairing aircraft structures
CFRP Repair – Repair of Tomorrow

Automation will not stop tomorrow!
**CFRP Repair – Bolted vs. Bonded**

**Repair scenario today**

**Scenario A:**
Damage small and slow degradation, load carrying capability after potential disbond within inspection threshold above L.L.
⇒ Bonded repair allowed

**Scenario B:**
Damage medium or medium degradation, load carrying capability after potential disbond within inspection threshold below L.L.
⇒ Only bolted repair allowed
Automated Repair – Bondline Control

"Intelligent adhesives" = The speaking matrix

- This reinforcement is stress-free cured
- There is no interlaminar stress in this bonded joint
- No thermal induced stress in this joint
- This repair is ok
Aircraft Maintenance in the CFRP Future – Conclusion

- We know the pieces, but we must build the maintenance system for the CFRP future
- Technology Readiness Level of maintenance process elements is different
- Some maintenance process elements are already available
- Some elements still need to be developed – SHM, CT calibrated US, EoD, bondline quality control
- All elements need to be standardized
- All elements need to be qualified
- Maintenance process for CFRP primary structure to be operational within next decade
- DLR is working along the whole process chain to provide solutions within requested timeframe
“In light of the fact that humanity is not able to learn from past mistakes …..we can not afford to make mistakes in the future.”

Ernst Ferstl