Adaptive Machining for Efficient Manufacture and Repair of CFRP Components

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Geometrical Adaptive Machining of Composite Components

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BCT's Background

- Established in 1986
- Location
  - Dortmund, Germany
  - Centre for Production Technology (CfP)
- Staff: A team of specialists
  - Engineers
  - Computer scientists
  - Mathematicians
- BCT's core know-how:
  Automated manufacture and repair of individually shaped parts
3D Measuring and Scanning

Task: Geometrically adaptive machining of individually shaped components

- Capturing of the component geometry is essential
- A multitude of measuring and scanning technologies are available
In-process 5-Axis Measuring and 6-Axis Scanning

**Tactile Probing**
- Standard on NC machines
- Cost effective
- Precise
- Slow
- Only single points

**Line Scanning**
- Integration via BCT solution
- Quick scanning
- Dense point cloud
- Less precise than probing
- Influence of surface properties
External Scanning Systems

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<th>Arm</th>
<th>Tracker</th>
<th>Robot</th>
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Adaptive Machining Configurations

In-Process Scanning
- Tactile probing or line scanning
- Direct measuring in the NC process
- Relatively expensive scanning time on NC machine
- No additional fixtures and part handling
- Measuring in the clamping position of machining

External Scanning
- Choice of ideal scanning technology
- Scanning and machining in parallel
- Less expensive scanning time on external scanning device
- Additional fixtures and part handling
- Clamping situation must be identical for scanning and machining!
Adaptive machining is used when components are shaped individually

- Machining with fixed NC programs is not feasible
- Tool paths must be adapted to the as-is geometry of the components
Best-fit vs. Adaption

**Best-fit:**
Correction of *position*

**Shape Adaption:**
Correction of *position* and *shape deviations*

Algorithms are **not depending** on application

Algorithms are **application-specific**

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Concept of OpenARMS

Open Adaptive Repair and Manufacturing Software

Setup mode:
for definition of adaptive machining projects

Run mode:
for adaptive machining in automatic production
Turbine Applications: Blades, Vanes & Blisks
Milling & Metal Deposition for Manufacturing & Repair
Turbine Applications: Casings & Combustors
Milling & Metal Deposition for Repair
Applications in the Field of CFRP

Geometrical deviations create problems in many steps of CFRP manufacturing and repair

- Adaptive machining for automated
  - Post-machining and
  - Repair / Reworking
Post-Machining of Sacrificial Material

Task: Keep part dimensions (thickness, height, ...) within tolerance
Approach: Adaptive machining with scanning, shape adaptation and 5-axis milling

Reference: European Collaborative Project “LOCOMACHS” - Low cost manufacturing and assembly of composite and hybrid structures
Post-Machining to Minimize Shimming

Task: Minimize shimming operations
Approach: Adaptive machining of mating surfaces in order to achieve flush fitting

Reference: European Collaborative Project “LOCOMACHS” - Low cost manufacturing and assembly of composite and hybrid structures
Task: Automation of scarfing process for patch repair
Approach: Mobile 5-axis milling system
Industrial Collaboration: Mobile 5-Axis Milling System for Patch Repair Preparation

- WIWeB: Customer & repair process development
  Wehrwissenschaftliches Institut für Werk- und Betriebsstoffe, Hauptmann Florian Feucht

- PRIMACON GmbH: Mobile machine

- Hufschmied GmbH: Cutting tools

- BCT GmbH: Software, scanning, integration
Selected Material Removal Technology: Milling

- Optimal macroscopic geometry of milled surface
- Optimal microscopic surface condition for perfect bonding
- Fast and reliable process
Optimization of Milling Strategies and Tools

- Development and testing of cutting tools
- Cylindrical cutting tools with special edge geometries
- 5-axis milling strategies
Intense Investigations and Testing

- Selection of best surface activation and bonding technology
- Nearly 100% strength of patched area compared with original condition
- Proven patch repair process chain
Cutting Tools

- Broad experience in composite cutting tools
- Highly specialized cutting edge geometries
- Extremely high material removal rate and long tool life
Mobile 5-Axis Milling Machine

- Lightweight mobile machine with vacuum clamping
- 5-axis milling with high-speed spindle
- Integrated line scanning sensor
Definition of Scarfing Geometry

- Patch patterns of all kinds via 2D / 3-axis pocket milling programs
- Integrated NC path generator for circular and rectangular patches
- Special shapes via CAM interface
Optical Scanning

- Machine-integrated line scanning
- Automatic capture of topology of unknown repair area
- Precise optical scanning
Adaptation

- 3D surface model generated from scanning data
- Transfer of 2D/3-axis master milling programs onto 3D as-is geometry
- Geometrically adapted 5-axis NC programs
Conclusions

- Deviations from nominal shape play a decisive role in manufacturing and repair of composite components.

- Geometrically adaptive machining compensates shape deviations and inaccurate clamping positions.

- Many geometrically critical post-machining and repair processes can be automated.

- The automatic mobile repair system shows the huge capabilities of adaptive machining in composites applications.

- Further developments are on the work plan: Load path optimized scarfing, integration of NDT and surface activation, applications in wind rotor blades and automotive.
Thank you for your attention!