Development of flexible systems for automated assembly and machining of large CFRP structures

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Assembly Technology
Joining Technology
Machining Technology
Metrology / Robotics
Overview

1. Introduction / State of the Art

2. Generic Flexible Automated Holding Fixture

3. Automated Measurement of Machine/Grippers

4. Automated Measurement of Part Geometry

5. Shape and Position Adjustment

6. Adaptive Mounting and Machining Processes

7. Summary
State-of-the-Art Assembly Systems

- Heavy-duty holding-fixtures of steel which require a specific foundation
- Expensive fabrication due to positioning tolerances of mechanical stops that define the part geometry
- Time-consuming measurement and adjustment processes
- Specially designed for a specific part and so unable to react to design changes
- Manual assembly procedures due to unique geometry of each part

Source: Airbus
Approach for Flexible Automated Holding Fixtures

- Steel support frame
  - Between floor & actuators
  - Inexpensive fabrication
- Actuators
  - High position accuracy
  - From 1-DoF to 6-DoF
- Flexible vacuum grippers
  - Between part & actuators
  - Exchangeable/identifiable
- Automated measurement of part and machine
- Adaptive mounting and machining processes using standard industrial robots

Generic Prototype for Flexible Holding Fixture
Generic Prototype for Flexible Holding Fixture

- Flexible steel support frame
  - Horizontal/vertical robot field
  - 3x4 grid
- 6 hexapod robots
  - High stiffness
  - Position accuracy < 100μm
  - 6-Degrees of Freedom
- Flexible vacuum grippers
  - Non-part specific
  - Triangular/passive
  - Half spherical mech. stops
  - F/T sensors
Automated Measurement of Machine/Grippers

- World coordinate system as global absolute reference
- Identification of robot bases $S^B$ to world coordinate system $S^W$
  - $T^B_W = (T^R_W)^{-1}T^B_R$
- Identification of gripper $S^G$ to TCP coordinate system $S^{TCP}$
  - $T^B_R = T^G_R (T^G_{TCP})^{-1} (T^B_{TCP})^{-1}$
Automated Measurement of Part Geometry

- Measurement of
  - CFRP-part shape
  - CFRP-part position
  - Components (e.g. clips, frames)

- Use of a non-contact, high precision, laser based system
  - Laser Radar (Nikon Metrology)
  - Laser Tracker/T-Scan (Leica)

- Comparison to CAD-drawings to obtain part deviations
  - Input for shape and position adjustment
Shape and Position Adjustment

- Iterative algorithm
  - Part shape/position measurement
  - Comparison to CAD
  - Inside tolerances? → yes/no
  - Calculation of adjustment
  - Next iteration
- Integration of force information
  - Grippers with 6D-F/T sensors
- Best-Fit of minimal shape deviations and stress reduction
  - Tolerance management
  - Gap reduction
Video

Deformation Force Measurement as a function of gap & component geometry
Adhesive Bonding Technology and Surfaces

Adaptive Mounting and Machining Processes

- Each CFRP-Part has a unique geometry
  → Teaching methods cannot be applied
- Hierarchical robot calibration
  - Improvement of absolute accuracy of standard industrial robots
- Sensor-aided CAD-CAM tools
  - Adaptive path planning for industrial robots to satisfy unique geometry
## Flexible Machining of CFRP Structures

### Conventional Machining
- one spindle for all machining tasks, no parallel machining
- tactile, time-consuming part measurement
- no established, reliable process monitoring
- high investment costs (> 5 Mio. €)
- long lead time

### Robot Based Machining
- parallel machining by several robots / spindles
- non-tactile, fully automated measurement
- fully integrated process monitoring, process reliability: +40%
- investment costs: -30%
- lead time: -50% [by parallel processing]
Flexible Machining of CFRP Structures - Challenges

**Process Monitoring**
- temperature
- force
- wear state
- tool break
- edge monitoring
- spindle power

**Machining Process**
- tool type
- tool diameter
- spindle speed
- feed rate
- machining strategy

**Dust Removal**
- removal strategy
- power
- filter
- adaptive removal systems

**Machining System**
- accuracy
- stiffness
- vibration behavior
- offline programming
Machining Test Facility at CFK NORD, Stade
Summary

- Technologies
  - Flexible holding fixtures
  - Automated part geometry and machine measurement
  - Shape and position adjustment
  - Robot calibration and sensor-aided CAD-CAM tools

- Applications
  - Assembly processes (i.e. adhesive joining of frames)
  - Machining of parts (i.e. milling of windows)

- Outcome
  - Reduction of production costs
  - Reduction of cycle times -> Increase of Production Rate
Thank you for your attention!

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