Perspectives of CAx-Technologies for Flexible Process Planning in Modern Production Environments

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Production Engineering in Aachen

Prof. Dr.-Ing. Dr.-Ing. E.h. Dr. h.c. Dr. h.c. Fritz Klocke
Prof. Dr.-Ing. Christian Brecher
Prof. Dr.-Ing. Robert Schmitt
Prof. Dr.-Ing. Dipl.-Wirt. Ing. Günther Schuh
RWTH Aachen and Fraunhofer-Gesellschaft

Fraunhofer-Gesellschaft
- More than 80 institutes and facilities at 40 locations in Germany
- 20,000 employees
- Approx. € 1.8 billion research funds per year, € 1.5 billion through research contracts
- 3 institutes in Aachen

RWTH Aachen University
- Founded in 1870
- 35,800 students

Faculty of Mechanical Engineering
- 10,100 students (incl. 2,200 first year students)
- 62 professors
- 2,600 employees
- 140 graduates per year
Production Technology in Aachen

Laboratory for Machine Tools and Production Engineering (WZL)
- RWTH Aachen University institute
- Founded in 1906
- 740 employees
- 16,000 m² offices and laboratories

Fraunhofer Institute for Production Technology IPT
- Fraunhofer-Gesellschaft institute
- Founded in 1980
- 380 employees
- 3,000 m² offices and laboratories
- Certified to DIN EN ISO 9001:2008
### Organizational Chart

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<th>Production Quality and Metrology</th>
<th>Technology Management</th>
<th>Fraunhofer Project Group Mechatronic Systems Design, Paderborn</th>
<th>Fraunhofer-Center for Manufacturing Innovation CMI, Boston/USA</th>
<th>Administration and Technical Services</th>
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<td>– Precision machines and automation technology</td>
<td>– Production metrology</td>
<td>– Technology Planning</td>
<td>– Control engineering</td>
<td>– Fiber optics and optoelectronic components</td>
<td>– Technical Services</td>
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<td>– Technical Purchasing</td>
<td>– Software engineering</td>
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<td>– Mechanical micro-machining</td>
<td>– Public Relations</td>
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<td>– Fine machining and optics</td>
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<td>Prof. C. Brecher</td>
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<td>Dipl.-Ing. S. Bichmann</td>
<td>Dipl.-Ing. C. Henke</td>
<td>Dipl.-Ing. C. Wenzel</td>
<td>Prof. A. Sharon</td>
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<td>Dr.-Ing. T. Bergs</td>
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<td>J. von Heel</td>
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<td>51 scientists</td>
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<td>14 employees</td>
<td>22 administrative staff</td>
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<td>17 technicians</td>
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<td>1 mathematical technician</td>
<td>2 technicians</td>
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<td>34 technicians</td>
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<td></td>
<td>1 administrative staff</td>
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<td>7 trainees</td>
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Fraunhofer IPT
Process Technology

Fine Machining and Optics
- UP-Diamondturning and -milling, precision-grinding and -polishing, high precision glass molding, FE-process simulation, PVD tool coating

High Performance Cutting
- Multi-axis milling, precision-milling, and -turning, process- and system-modeling

Laser Material Processing
- Laser-based joining and surface structuring, laser-based machining and surface treatment, additive component manufacture and repair

CAx-Technologies
- CAx-Framework, Development of CAM-tools, NC-Simulation, NC-Code optimization and analysis
CAx-Technologies
Department at Fraunhofer IPT

»CAx-Framework« and CAx-Module Development

Milling / Grinding
Laser Material Deposition
Ultra-Precision Machining
Metrology
Laser Ablation

Analysis and Optimization

NC Data Analysis and Optimization
CAX Process Chain Evaluation

Source: Fraunhofer IPT / CAx-Technologies 2013
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Motivation
The ideal CAx-System

- What are features of an ideal CAx-System?
  - The model design is created once and all people involved in subsequent production processes can extract the required data
  - All process know-how gained during development and production ramp-up is preserved
  - Metrology data can be referenced to design models
  - In repair processes, workpiece defects are detected semi-automatically based on metrology data; repair processes can be calculated from this
  - Analysis of part failure during operation allows to identify production faults (ideally part specific)
  - ...

Motivation
Production Data in a Product Life Cycle

Data
- Constructions-Data in 2D/3D, Metadata
- CAM-Strategies and process parameter
- Machine- & Control-daten
- Optimized NC-Daten

Product-Life Cycle
- Design
- Process Planning and Simulation

Demands: Availability of Process and Product data throughout the whole life cycle
- Data access, analysis- and evaluation methods
- Optimized data handling along the product life cycle

Repair planning und Simulation
- Product qualification
- CAx-Repair-Process chain
- Adaptive repair strategies
- current workpiece shape
- inspection data

Operation & Inspection
- Monitoring during operation
- QA data

Processing
- Machine-NC-Data
- Process-monitoring

Archive /
Learn for Future
- Clamping / Referencing

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State-of-the-Art

Current Situation in Production Environments

- **Data Driven Process Chains**
  - All relevant production data stored and exchanged electronically

- **Several Heterogeneous Sources of Data**
  - Process Planning \(\rightarrow\) Process Parameter
  - QA Systems \(\rightarrow\) Metrology Data
  - CAD/CAM Software Tools \(\rightarrow\) NC Data
  - Monitoring Systems \(\rightarrow\) Machining Data

- **Data transfer / Interfaces**
  - Different protocols between different systems

- **Know-how Preservation**
  - Connection to databases (SQL, Postgres, …)

- **Big Data**
  - Increasing amount of data, \(\rightarrow\) scalable
    (2 Exabytes of data in 2012 generated by industries worldwide)

CAD/CAM, Machining and Metrology Examples
Source: Siemens PLM, Starrag, Werth
State-of-the-Art
Current Situation: PLM-Systems

Approaches in respect to connectivity and Big Data:
- Dassault Systèmes:
  - Exalead (search functionality)
  - Netvibes (Social Networking)
  - 3DLive (visualizing)
- Siemens PLM Software:
  - Teamcenter
  - Active Workplace (search functionality)
  - HD-PLM (visualizing)

Companies are often not aware of the possibilities
- of the benefits of connected CAM/PLM Systems
- of advantages of database systems in their production environment
- how to generate economic value from those systems
State-of-the-Art
CAD/CAM Systems

- **Popular Systems in Europe:**
  - Siemens: PLM: Siemens NX
  - Autodesk: AutoCAD / InventorCAM
  - Dassault: Catia V5/V6
  - PTC: ProEngineer

- **Strong in mainstream CAD / CAM applications**
- **Connection to PLM systems possible**

- **But:**
  - No flexible integration of custom processes
  - No established standard for data exchange across the borders of each ‘ecosystem’

Source: Siemens PLM, Dassault Systemes
State-of-the-Art
Current Situation: Data Formats

- Main Geometry Formats:
  - IGES (Version 5 ANSI standard since 1996)
    - ASCII-based → large file sizes
    - Almost standard in machining environments for geometry definition and exchange
  - STEP / STEP-NC (DIN EN ISO 10303)
    - Allows flexible definition of data structures that can contain additional production relevant data
    - Basically the whole product lifecycle can be represented in STEP data structures
    - No widespread acceptance of this format in the machining community
  - DXF
    - Long tradition, often labeled industry standard
    - Not established in machining community
  - Other (STL, JT, ...)
    - Proprietary formats / company or software specific
State-of-the-Art

Data Management

- Centralized document server for technical content (e.g. Siemens Teamcenter)
  - Convenient data access (e.g. CIFS/NFS and/or API)
  - Implementation of rights management for different users / roles

- Revisions / Versioning
  - Ensure the usage of current version of the design model
  - Ability for switching to older versions
  - Check-out of documents and simultaneous blocking

- Provide Comprehensive Analysis Tools through centralized Data Administration
  - FEM-Analysis
  - Model Quality Analysis
  - Metrology Evaluation and Comparison with Data Models
  - Cost calculations and Review of Processes Chains

- Usage of Big-Data Tools for reliable and scalable Data Management
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### Areas of Action

#### “CAx-Framework”
- Flexible platform for integration of CAx modules
  - CAD, Technology Databases
  - Machining and laser applications
  - Ultra precision manufacturing
  - Metrology and process monitoring
  - Process and machine simulation modules

#### CAx-Modules
- Implementation of new production-technological methods in prototype software modules
- Strategic cooperation with industrial customers and development partners with the objective of product commercialization

#### NC Data Optimization
- Software “NCProfiler” for analysis and optimization of NC data
  - Simulation of NC-data within kinematics and controller specific context
  - Check of critical toolpath areas
  - Broad postprocessor functionality

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Source: Fraunhofer IPT / CAx-Technologies 2013
CAx Developments at the Fraunhofer IPT
»CAx-Framework« and »NCProfiler«

» CAx-Framework «

Data
- CAD-Model workpiece

Technology parameter
- process parameter
- machine configurations
- system specs

CAM-Module
- Intuitive user interfaces
- Application specific toolpath strategies
- toolpath calculation

Simulation-module

Verification

» NCProfiler «

New NC-Code

Existant NC-Code

Optimized NC-Code

NC-Data-analysis and optimization
- Analysis and Optimization of NC-Data
  - Kinematics
  - Dynamics
  - Machine Control

Postprocessor
- Calculation of machine-specific NC-Code

Optimized Machine NC-Code

Source: Fraunhofer IPT / CAx-Technologies 2013
CAx Developments at the Fraunhofer IPT
CAD Model Quality

CAD Model

Design Optimization

CAM Planning

Inspection Planning

→ CAD Model Quality is very important!

Source: Fraunhofer IPT / CAx-Technologies 2013

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CAx Developments at the Fraunhofer IPT
CAM Planning for Adaptive Machining

CAD model

Geometric comparison with tolerances

Define material pre-position

Calculate tool position on material

Machining process → Step 1

Machining process → Step 2

Machining process → Step 3

Simulation/Verifications
→ Material removal
→ Machine kinematics

Toolpath calculation
→ Algorithms for adaptive machining

Process parameters
→ Feed and speed
→ Cutting loads
→ Surface quality

Next iteration

Calculated NC data

Measuring data input

Measuring

Calculation of cutting forces

Source: Fraunhofer IPT / CAx-Technologies 2013
CAx Developments at the Fraunhofer IPT
»The Aachen Process Chain: Repair of a Gas Turbine Blade«

»IPT-CAx-Framework« – Data-Consistent Software-Platform

Geometry Acquisition
Preparation Milling
Machine-integrated optical Scanning
Milling Machine
Laser Material Deposition
Laser Processing Machine
Geometry Acquisition
Maschine-integrated optical Scanning
Recontouring by adaptive Milling / Grinding
Milling Machine
Universal Clamping Technique

Repaired Gasturbine-Blade

Source: Fraunhofer IPT / CAx-Technologies 2013
Example for large file sizes: Metrology Data

- Objective: Reduction of footprint / memory consumption
  - Optimization of data structures
  - Removal of metrology data within specs: Only deviations are recorded long-term
  - Transformation into geometric primitives where possible

- Example Computer Tomography
  - Automated detection of defective regions and storing of the related metrology data

- Decision if efficient storage (few accesses per time) or indexing (fast access - frequent usage) is more appropriate

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Summary and Outlook

- Consideration of the whole process chain is necessary instead of optimizing single processes.
- Handling of flexible process chains within CAx-systems with standardized interfaces.
- Consistent data flow during the whole process chain increases productivity.
- Big Data issues are becoming more important in the near future.

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