



IFW

Institut für Fertigungstechnik
und Werkzeugmaschinen

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Challenges in software engineering for CPPS
from a mechanical engineering perspective

Dr.-Ing. Marcel Wichmann, 01.06.2023



Leibniz
Universität
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Produktionstechnisches
Zentrum Hannover



Semi-autonomous manufacturing cell for orthopedic implants



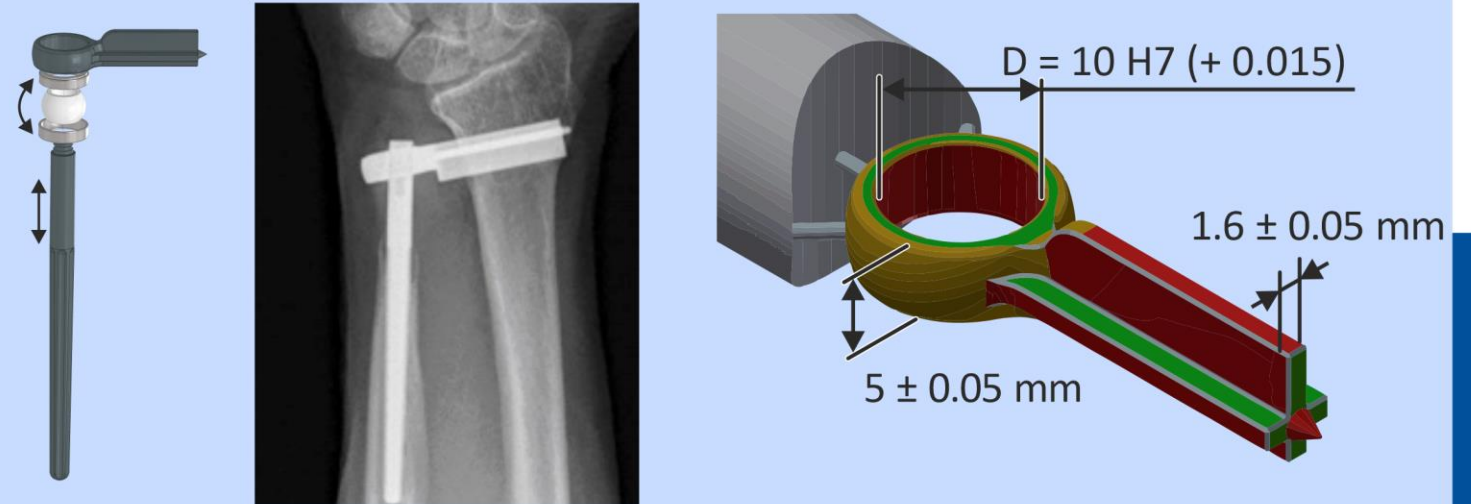
CPPS

Semi-autonomous manufacturing cell for orthopedic implants



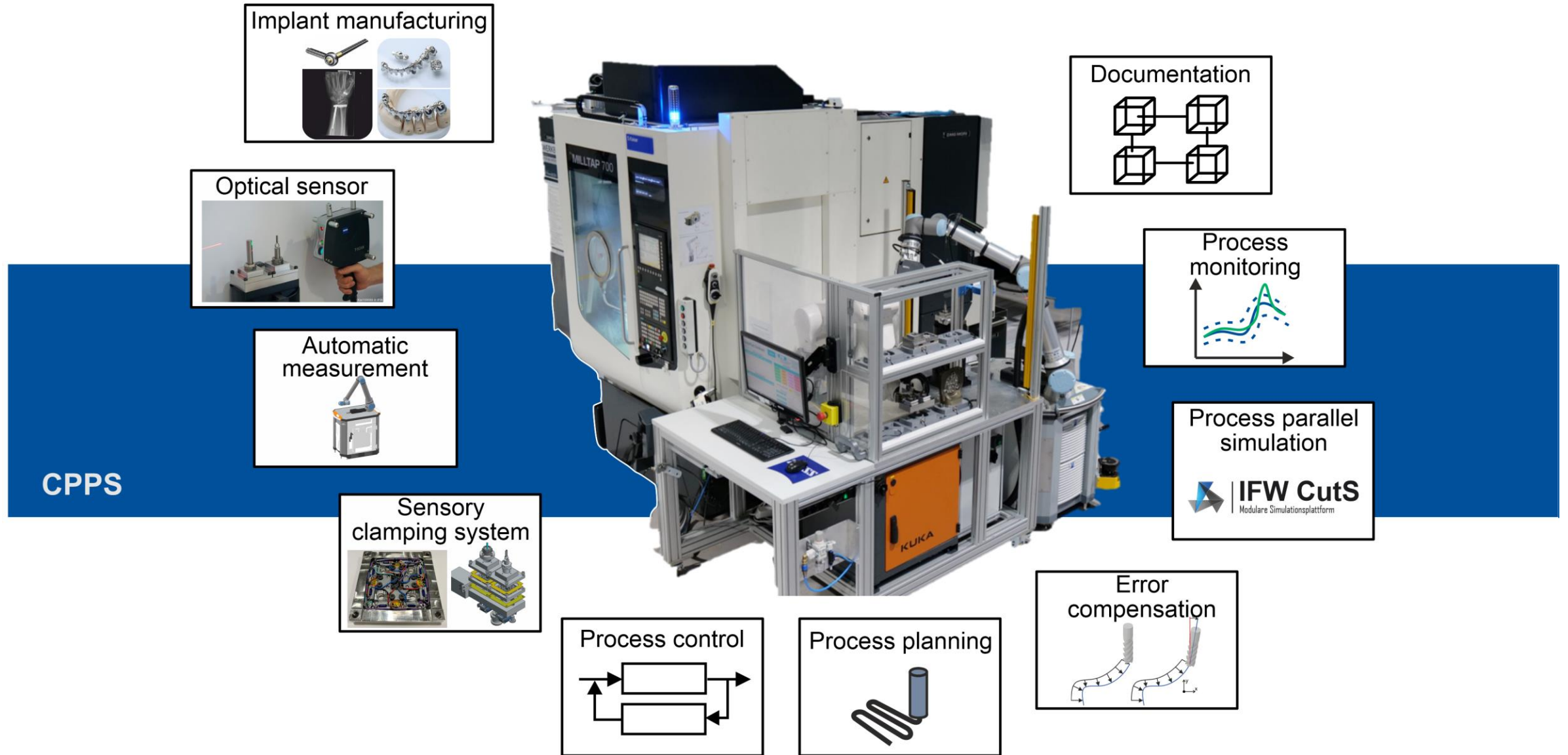
CPPS

Distal radioulnar joint endoprosthesis



- Material: Ti6Al7Nb
- Manufacturing in very small batches
- CAM planning with Siemens NX
- Production time approx. 40 minutes, number of tools: 6

Semi-autonomous manufacturing cell for orthopedic implants



Benefits and software engineering challenges

Benefits of a semi-autonomous manufacturing cell

- Automatic quality control
- Automated process planning
- Process control and error compensation
- Teach-in-free process monitoring
- Compliance with regulatory requirements

Software engineering challenges

- System and information complexity
- Product variability and Multidisciplinarity
- Knowledge management
- Data Analytics & AI (transfer learning, active learning, ...)



Agenda

1 Institute of Production Technology and Machine Tools (IFW)

2 Autonomous machine tool

2.1 Adaptive process planning in implant manufacturing

2.2 Digital Implant Lifecycle Management

3 Software Engineering for CPPS



Competencies of the IFW

IFW



Manufacturing Processes
(Dr.-Ing. Benjamin Bergmann)



Machines and Controls
(Dipl.-Ing. Heinrich Klemme)



Fiber Composites
(Dr.-Ing. Carsten Schmidt)

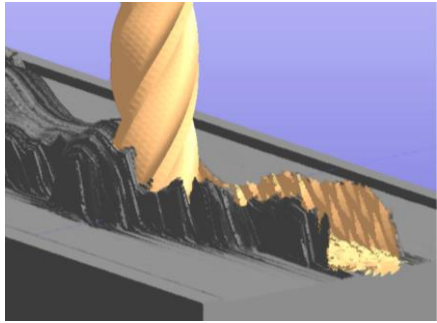


Production Systems
(M. Sc. Marcel Wichmann)

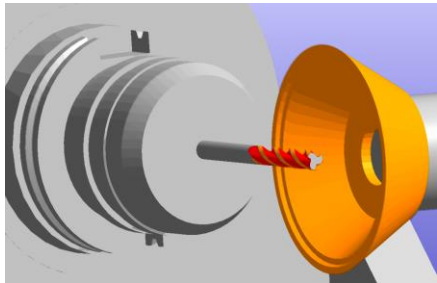


Mittelstand 4.0
(Dr.-Ing. Michael Rehe)

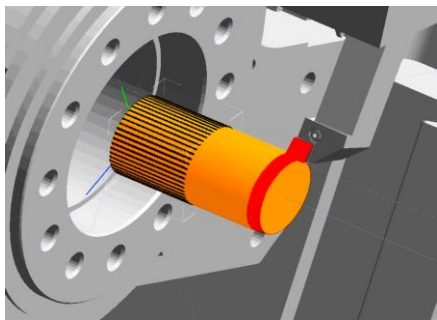
Technological NC-Simulation in IFW CutS



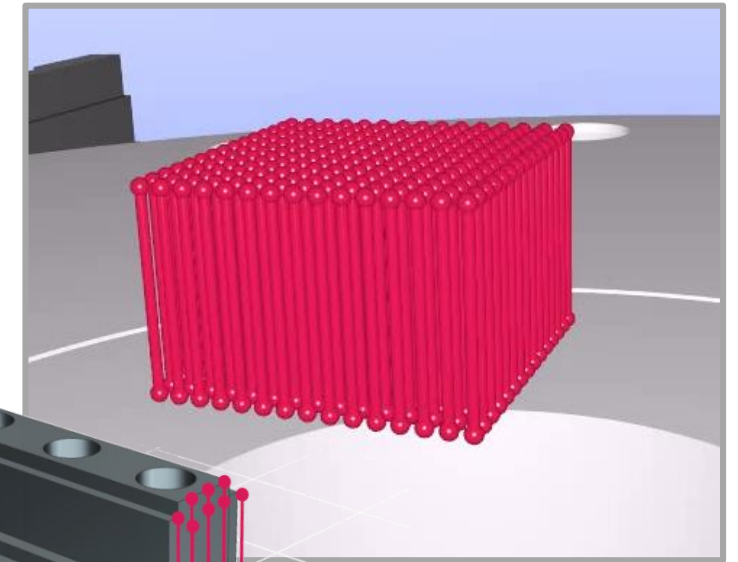
- Representation of actual workpiece geometries
- Machining with realistic tool models



- Modelling of complex kinematic movements
- Analysis of local cutting conditions



- Specific workpiece models
- Integration of further technological models
- Simulation of additive and subtractive manufacturing



**Material removal by
using a dixel model**

Identifying errors before they occur



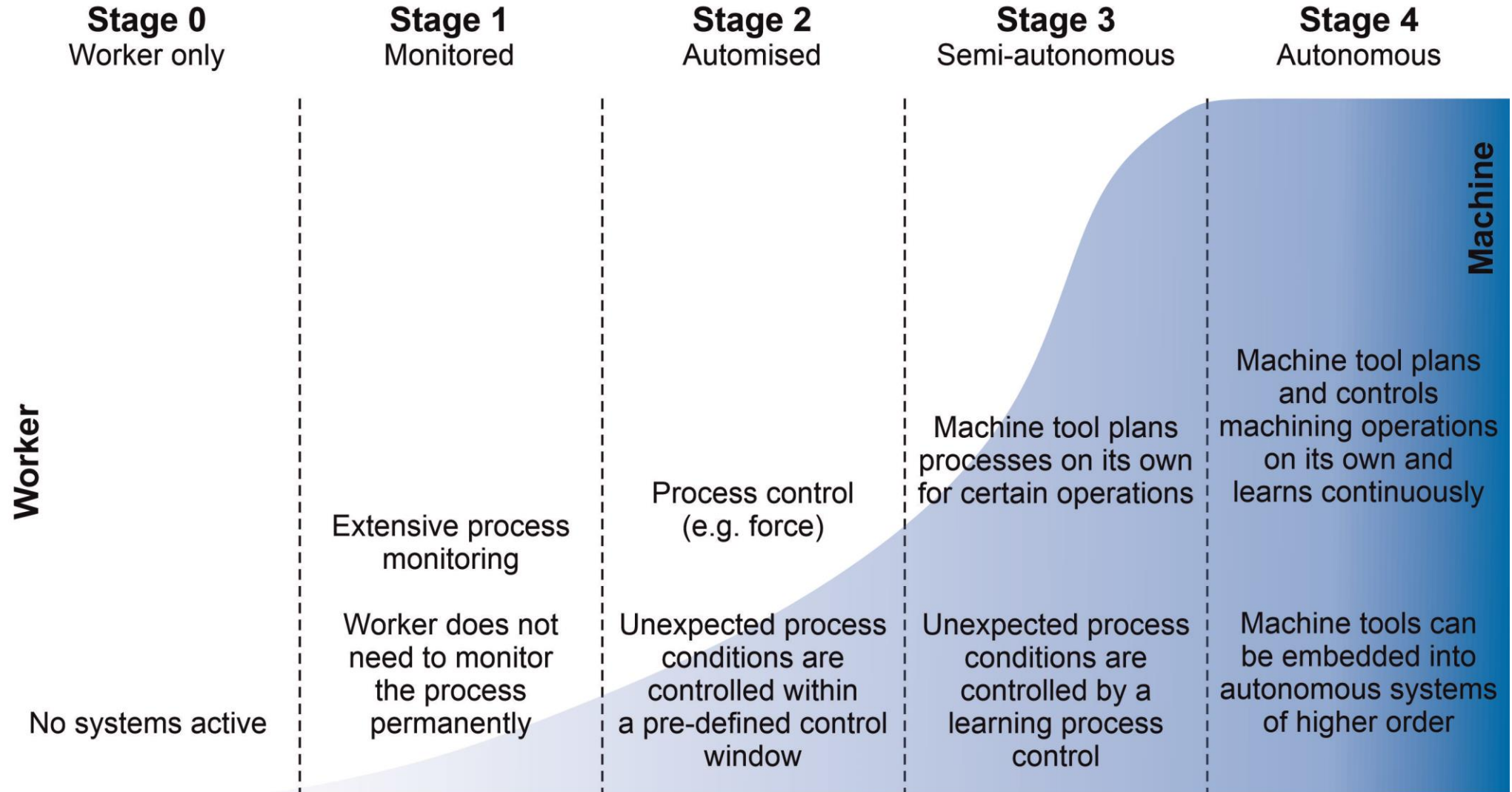
IFW CutS

Modulare Simulationsplattform

Autonomous machine tool

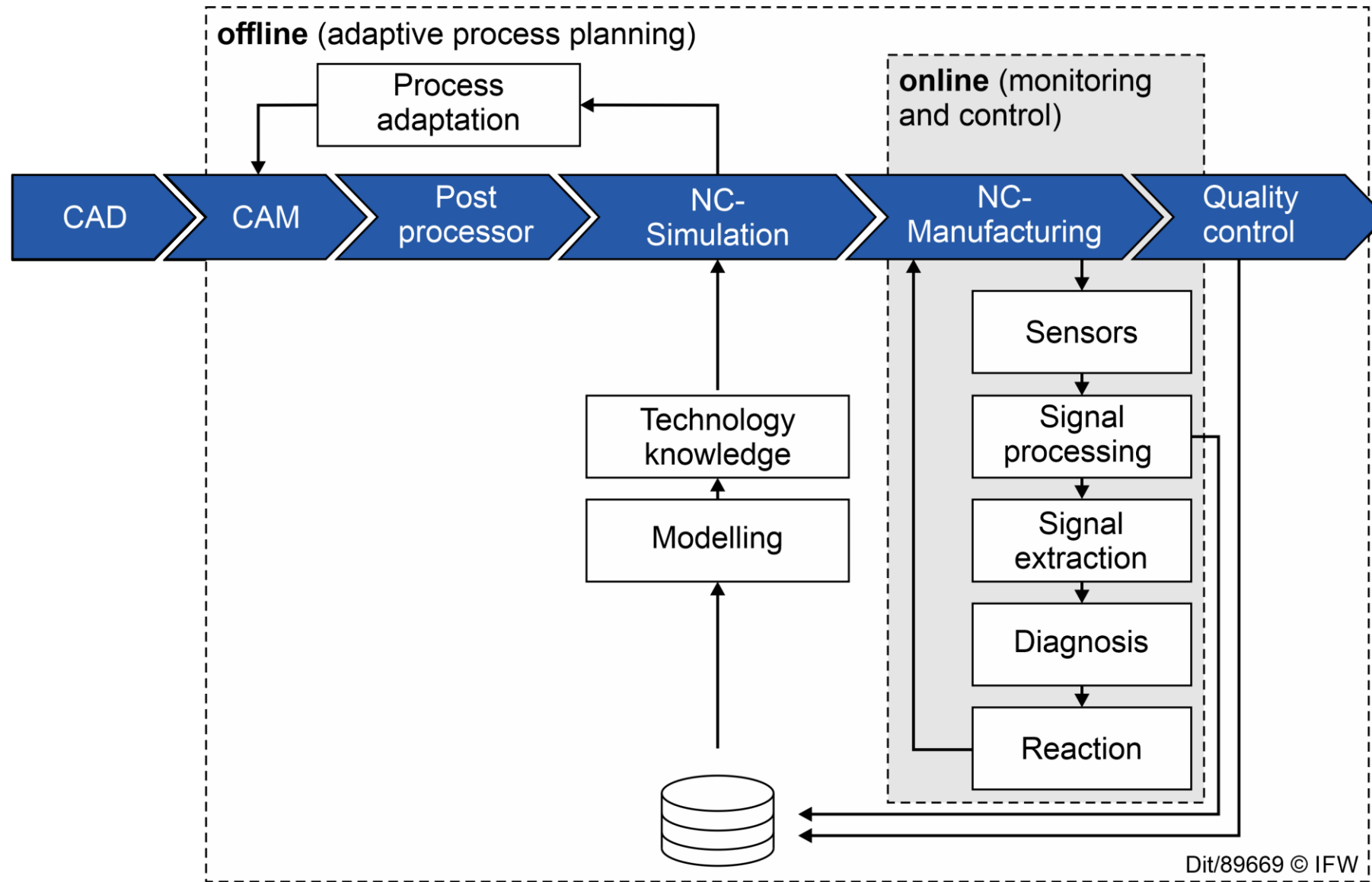
Autonomous machine tool

The five levels of autonomous production



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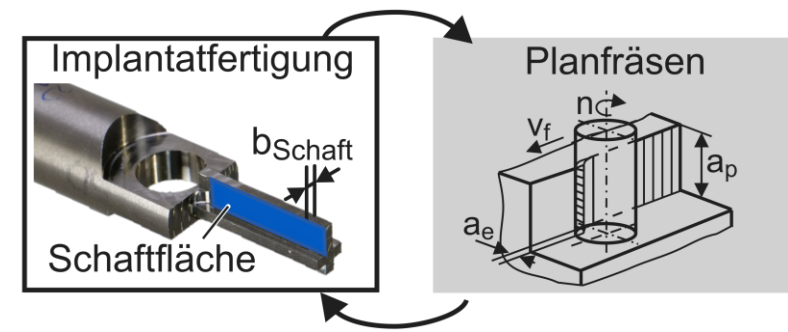
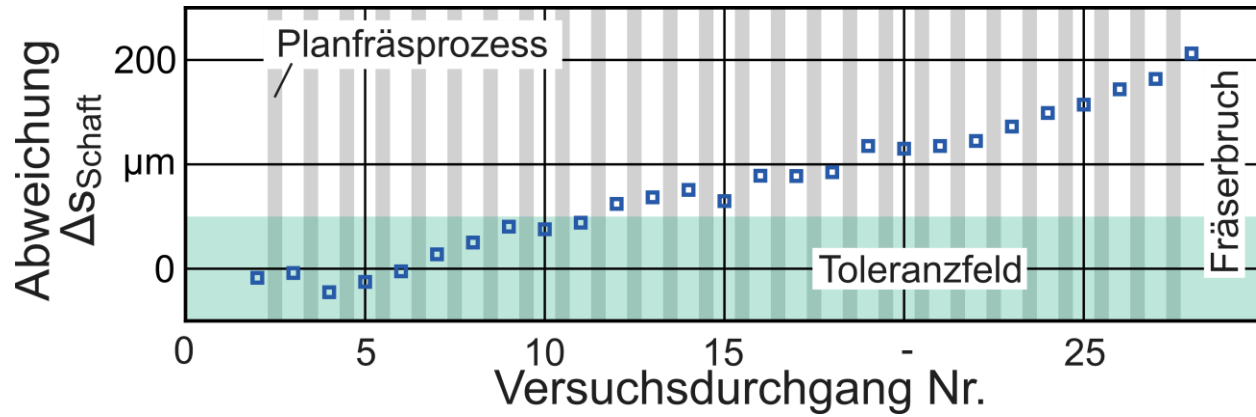
Control loops in an autonomous machine tool



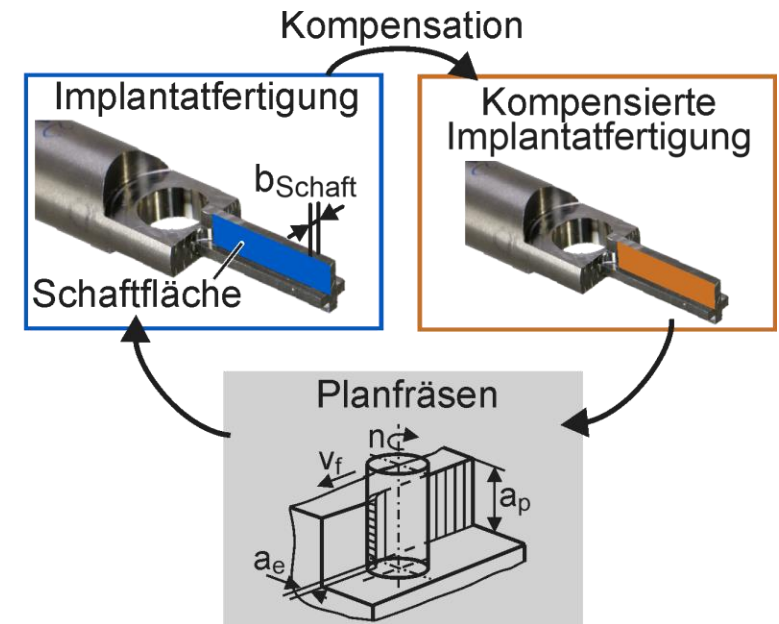
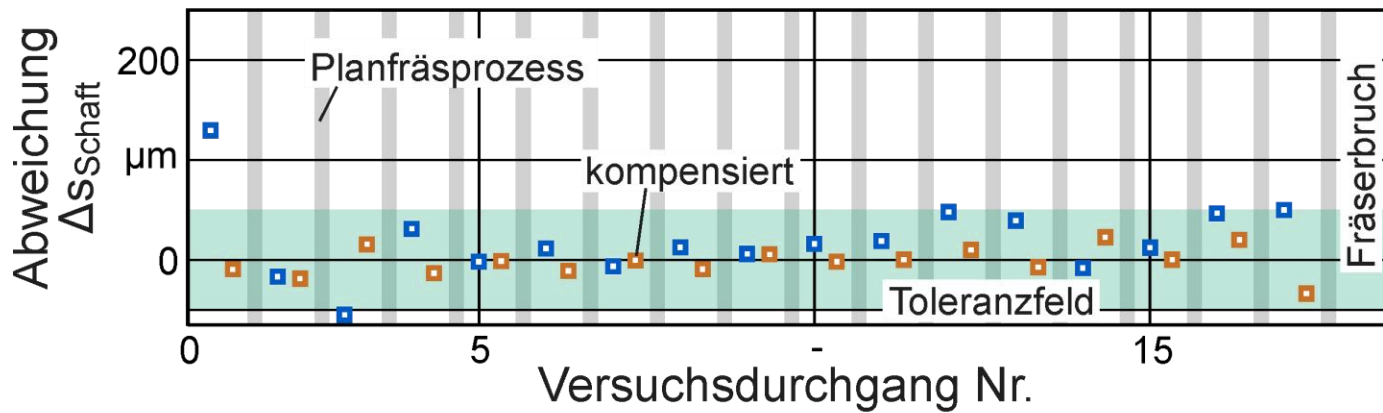
Adaptive process planning in implant manufacturing

Process adaption for error compensation in series production

Without process adaption



With process adaption



AI-based self-learning process adaptation

Problem definition

- Manufacturing data is not merged
- Knowledge remains at experienced staff
- Assistance systems in process planning are rigid

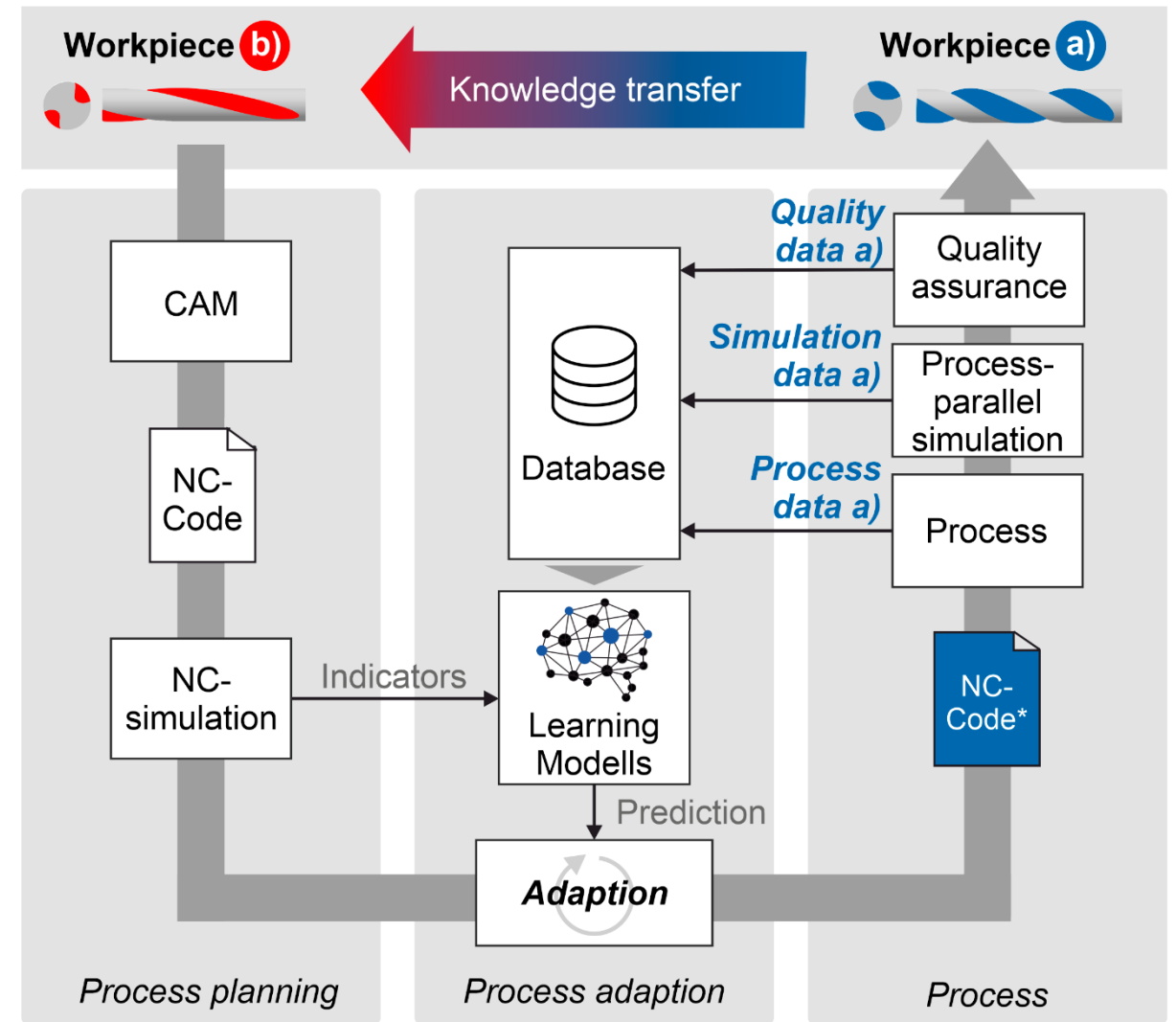
Objective

- Combination of different data types
- Simulation based process adaption
- Knowledge transfer to save resources

Approach

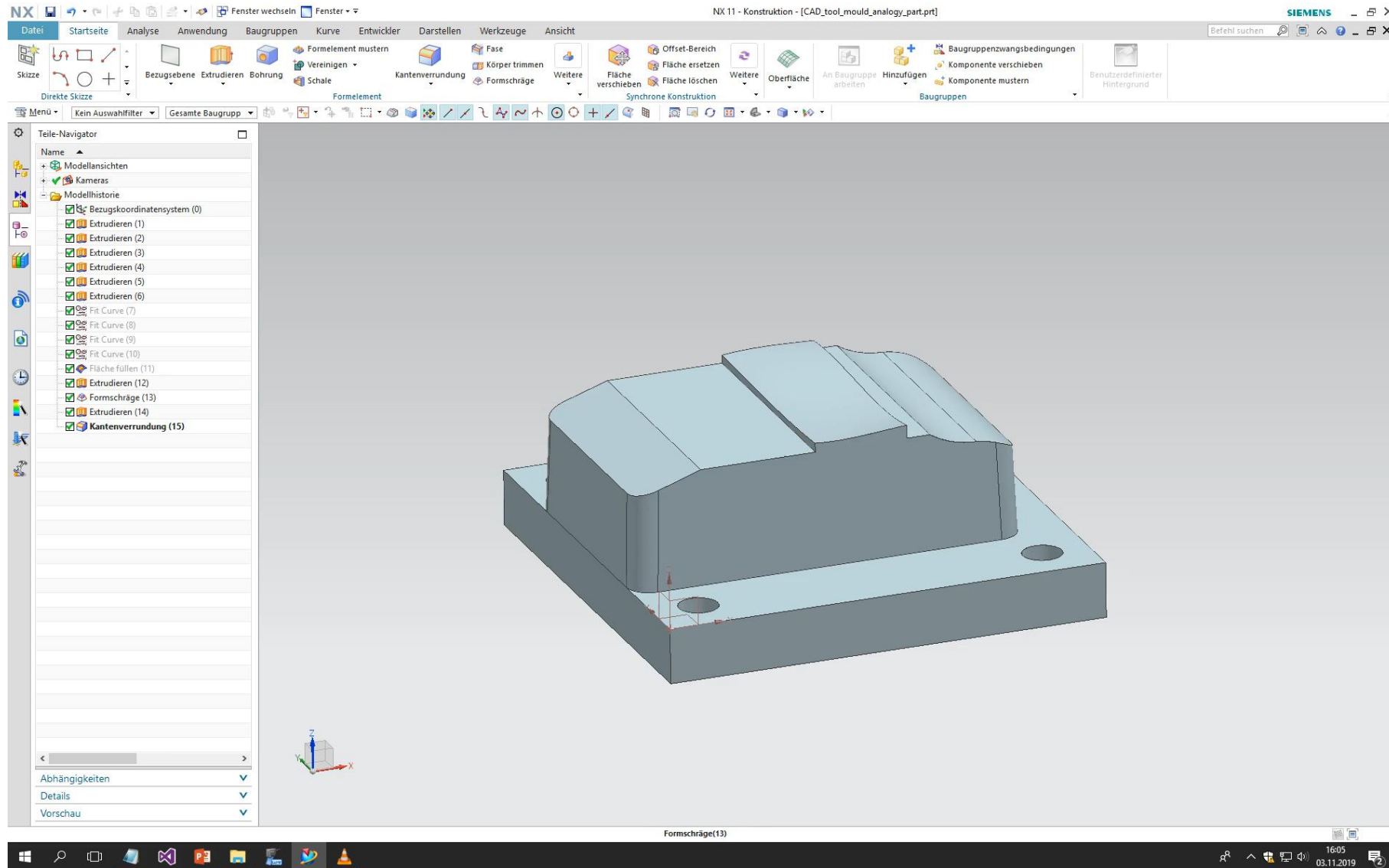


AI-based self-learning process adaptation by using digital twins in process planning

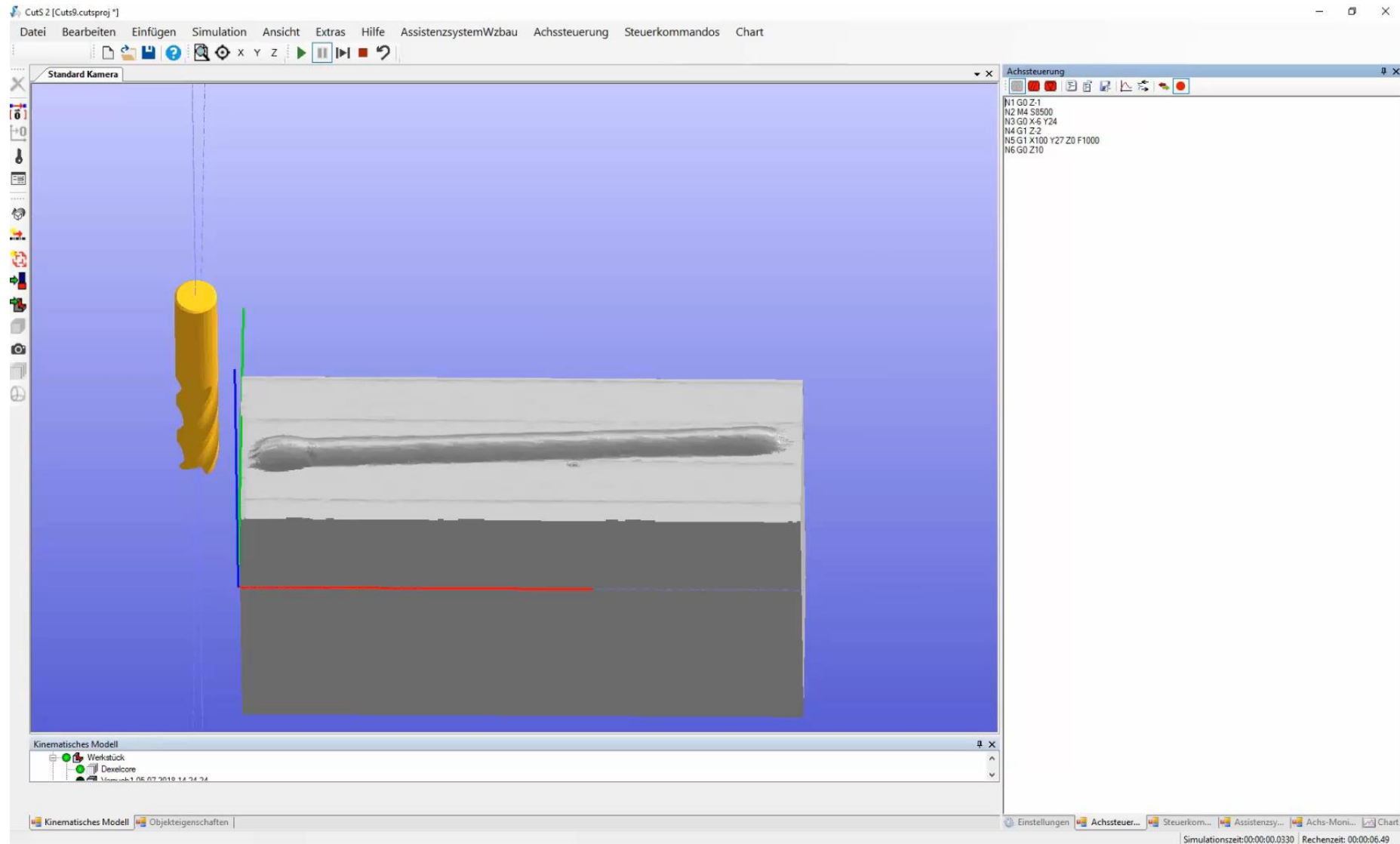


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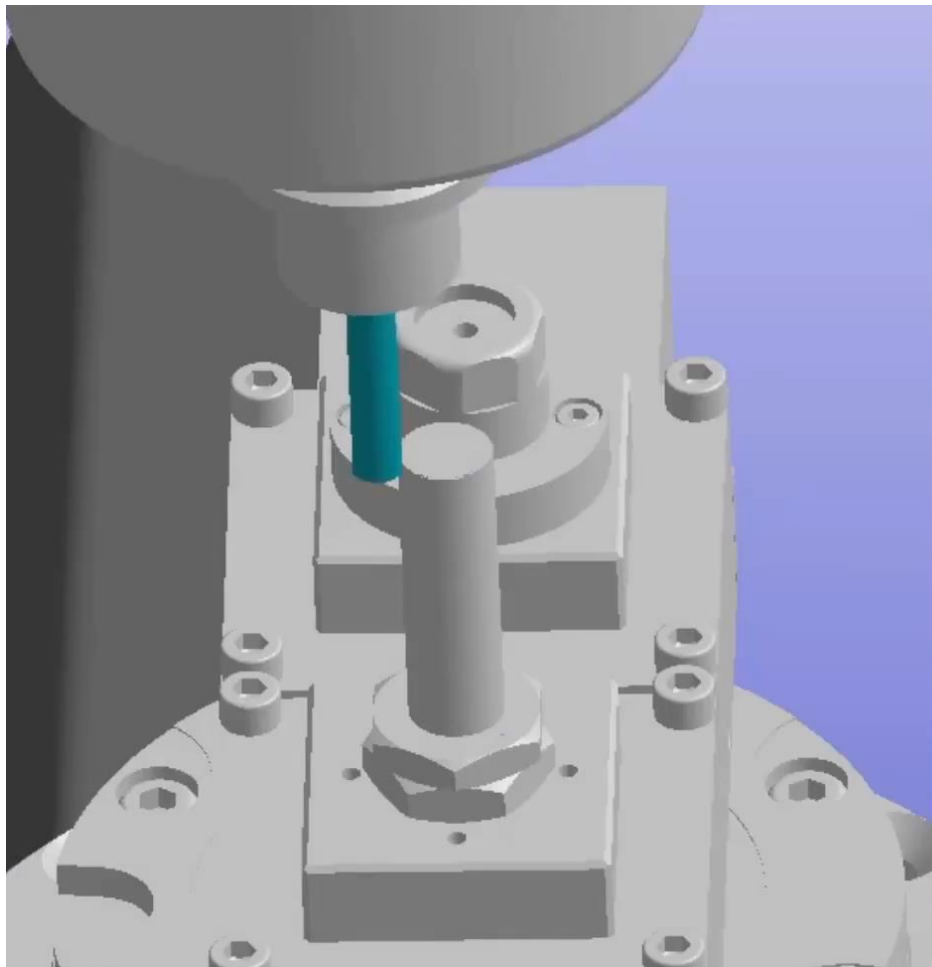
Automated process planning (CAM)



Process adaption by NC-simulation



Process parallel simulation as a soft sensor



Simulation – IFW CutS



Milling process – DMG Milltap 700

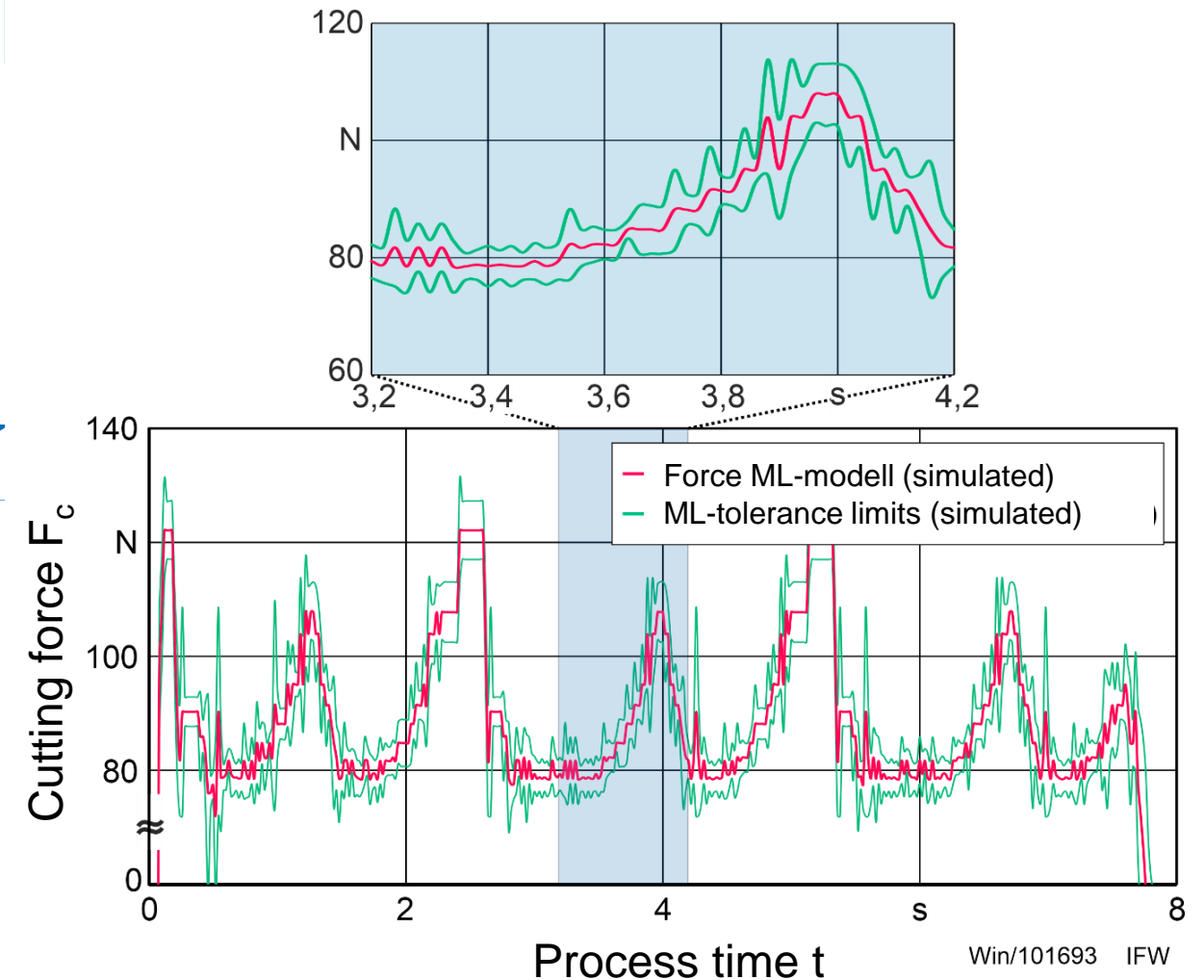
Process monitoring using simulation approaches

Set monitoring limits by a process simulation

- Force prediction by ML-Modell (ML.Net)
- Limit corresponds to the standard deviation of the modeled process forces

Process monitoring using IFW CutS

- Forces are measured in the cutting process and transferred to IFW CutS in real time
- If the limits are exceeded, the CNC machine is stopped automatically by IFW CutS.



Video of process monitoring (IFW CutS)

The screenshot displays the IFW CutS software interface, which is used for process monitoring and simulation. The main window is titled "CutS 2 [MillTap_MKSModel_TempoPlant_PÜ_Dexel_25.cutsproj *]".

Left Panel: Kinematisches Modell
 This panel shows a hierarchical tree of the simulation model. Key components include:

- MKS (Main Kinematic Structure)
- Tischmitte (Table Top)
- Drehpunkt (Rotation Point)
- NPV_A, NPV_C (Kinematic joints)
- G54 (Coordinate system)
- Werkstück_1 (Workpiece), Dexcelcore, Zylinder (Cylinder)
- Camera_1, Camera_2 (Viewports)
- Spindel (Spindle)
- LEERWERKZEUG (Empty Tool)
- Kugel (Ball)
- TestWerkzeug (Test Tool)
- Schaftfräser (End Mill)
- SF8-SECO-JS75S080, SF8-SECO-JS75S080, SF4-SECO-JS754040 (Cutting tools)

Bottom Left Panel: Objekteigenschaften
 This panel displays properties for the selected object (MKS):

- Allgemein:** Beschreibung, Bezeichnung: MKS
- Anzeige:** Sichtbar: **False**
- Sonstiges:** Camera: **Standard Kamera**, KinematicState: X-205.59344 A90 C270 Y-146.20483 Z-3, Teilbaupfad, TypeAlias: MachineModel, TypeDescription
- Transformation:** Rotation: 0:0:0, Skalierung: 1:1:1, Transformationsmatrix: 1:0:0:0:1:0:0:0:1:0:0:0:1, Translation: 0:0:0
- Bezeichnung:** (Empty field)

Main View: A 3D visualization of the cutting process. A grey cylindrical workpiece is being cut by a blue cylindrical tool. The background is a light blue gradient.

Right Panel: TempoPlantWindow
 This panel contains the monitoring dashboard:

- Status Prozessüberwachung:**
 - Prozessüberwachung inaktiv** (Red box)
 - Obere Überwachungsgrenze: 15,0 N
 - Aktuelle Prozesskraft: 0,200 N 0,0 N
 - Untere Überwachungsgrenze: 0,0 N
 - Feed Ovr: 50 %
- Simulation Prozessfehler:**
 - delta F [N]: 0.5
 - Buttons: Simuliere Prozesskraft zu hoch, Simuliere Prozesskraft zu niedrig
- Echzeitüberwachung:** (Green box)
- Graph:** A line graph showing force over time. The y-axis ranges from -10.0 to 25.0 N. The x-axis shows time points: 176.4, 180.8, 185.2, 189.6, 194.0, 198.4. The graph includes:
 - Kraftprognose (Green line)
 - Obere Überwachungsgrenze (Red line)
 - Untere Überwachungsgrenze (Blue line)
 - Ist-Kraft (Blue line)
- Controls:**
 - Offset Überwachungsgrenzen [N]: 5
 - Drosselung Grenzen [-]: 0,1
 - Sensitivität Dämpfung [N]: 5
 - Buttons: Maschine Start (Green), Maschine Stopp (Red)
 - Buttons: Override auslesen, Override schreiben

Bottom Status Bar:

- Einstellungen, AGLinkDC, TempoPlantWindow, ValuePredictionWindow
- Simulationszeit: 00:03:15.4 | Rechenzeit: 00:00:36.45

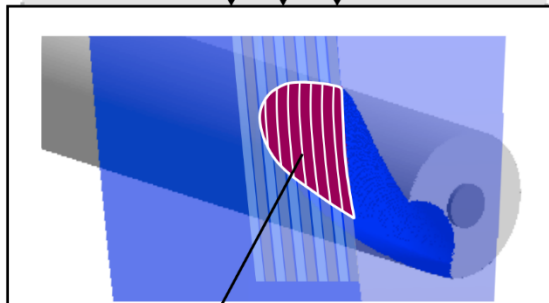
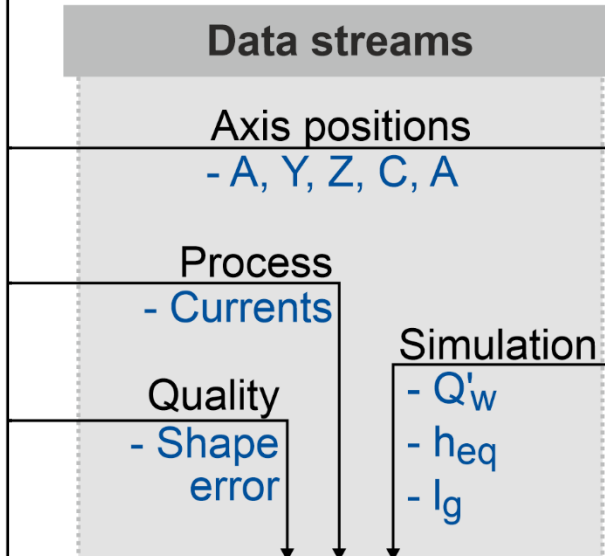
Digital Implant Lifecycle Management

Approach for single processes – Digital Twin in tool grinding



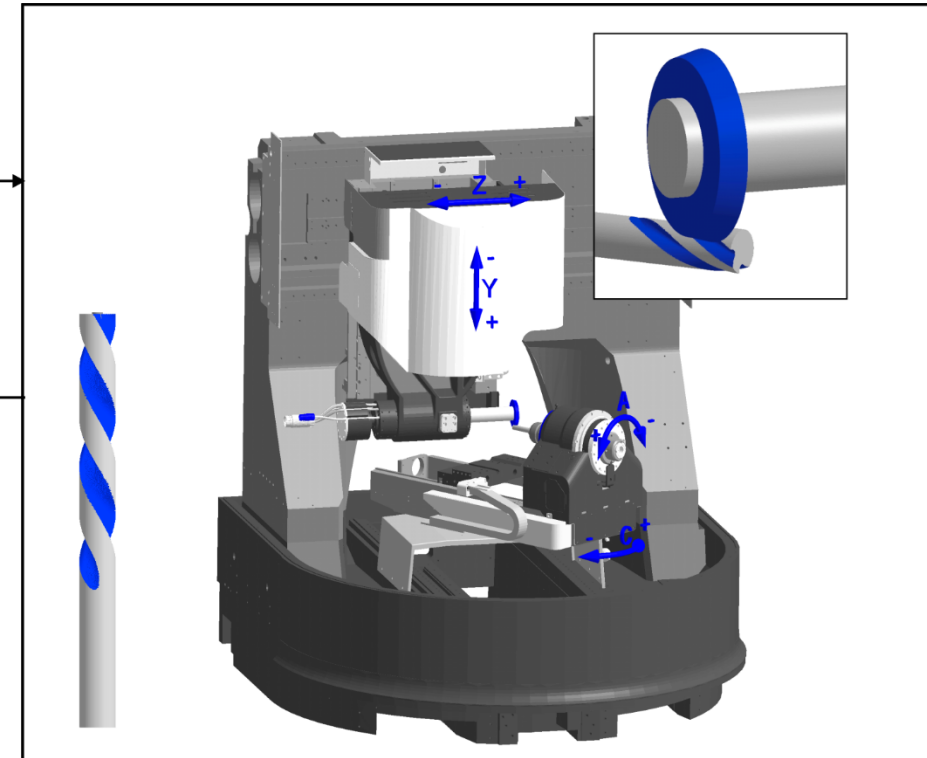
Manufacturing

- Machine control transfers axis data, spindle current and axis currents in 200 Hz
- Sensor data can be used additionally



Cutting conditions

Knowledge database



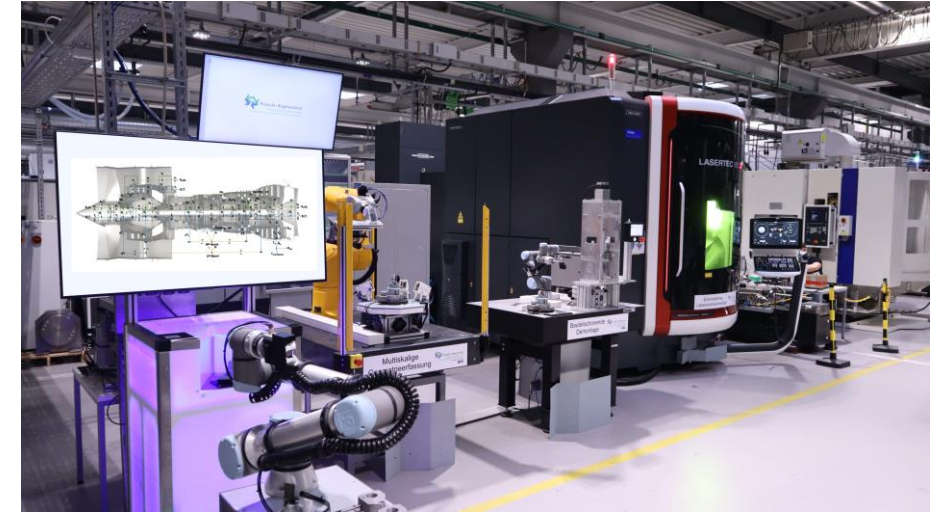
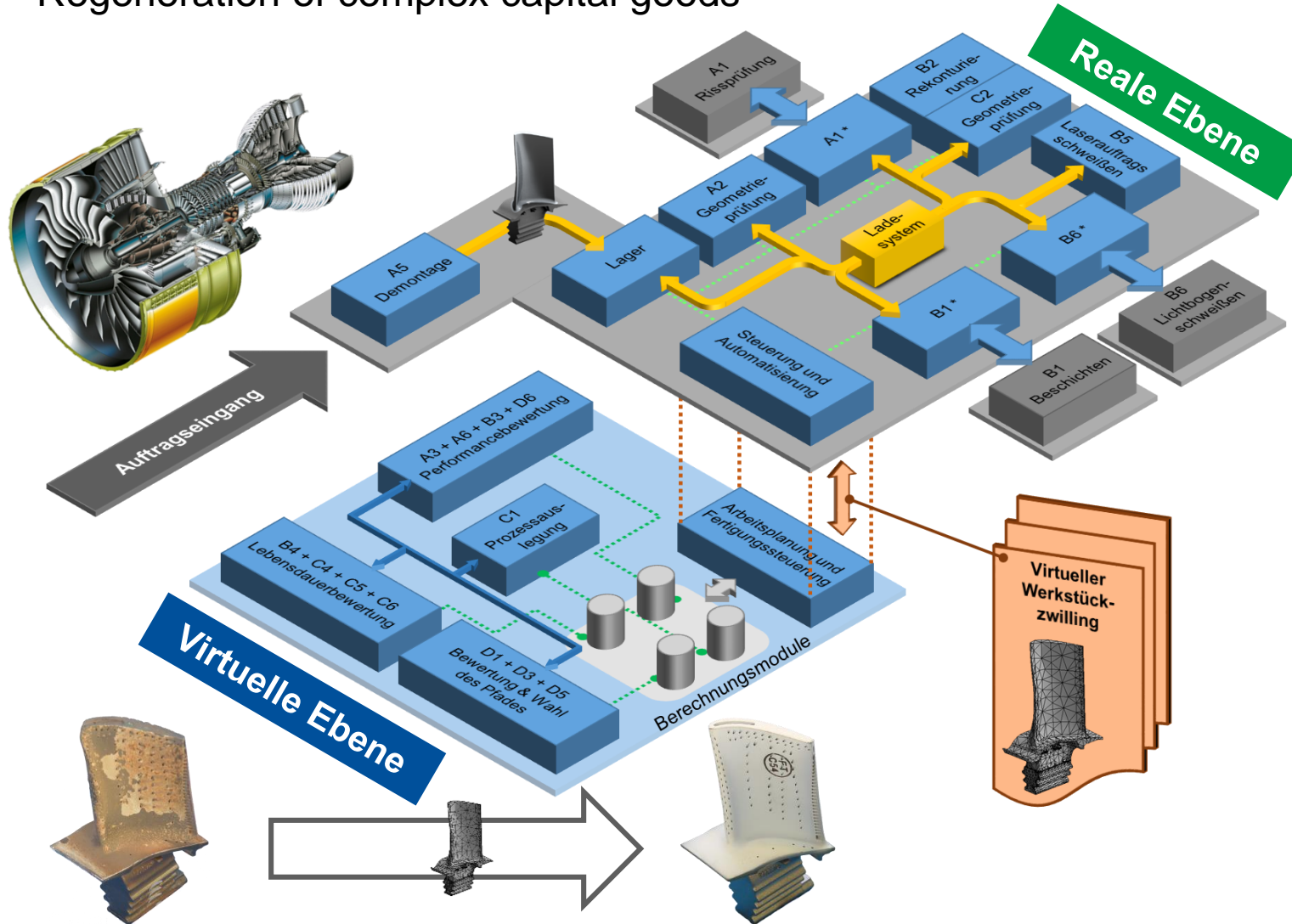
Material removal simulation

- Process-parallel material removal simulation uses the real axis data
- Calculation of the local cutting conditions

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Approach for process chains – Repair procedures for aircraft engines

Regeneration of complex capital goods



- **Digitalization:**
 Real level of the repair process
 ⇔ virtual level of the digital twin
- **Consideration:** Functional benefit of repairs
- **Benefits:** Automated decision making in complex systems

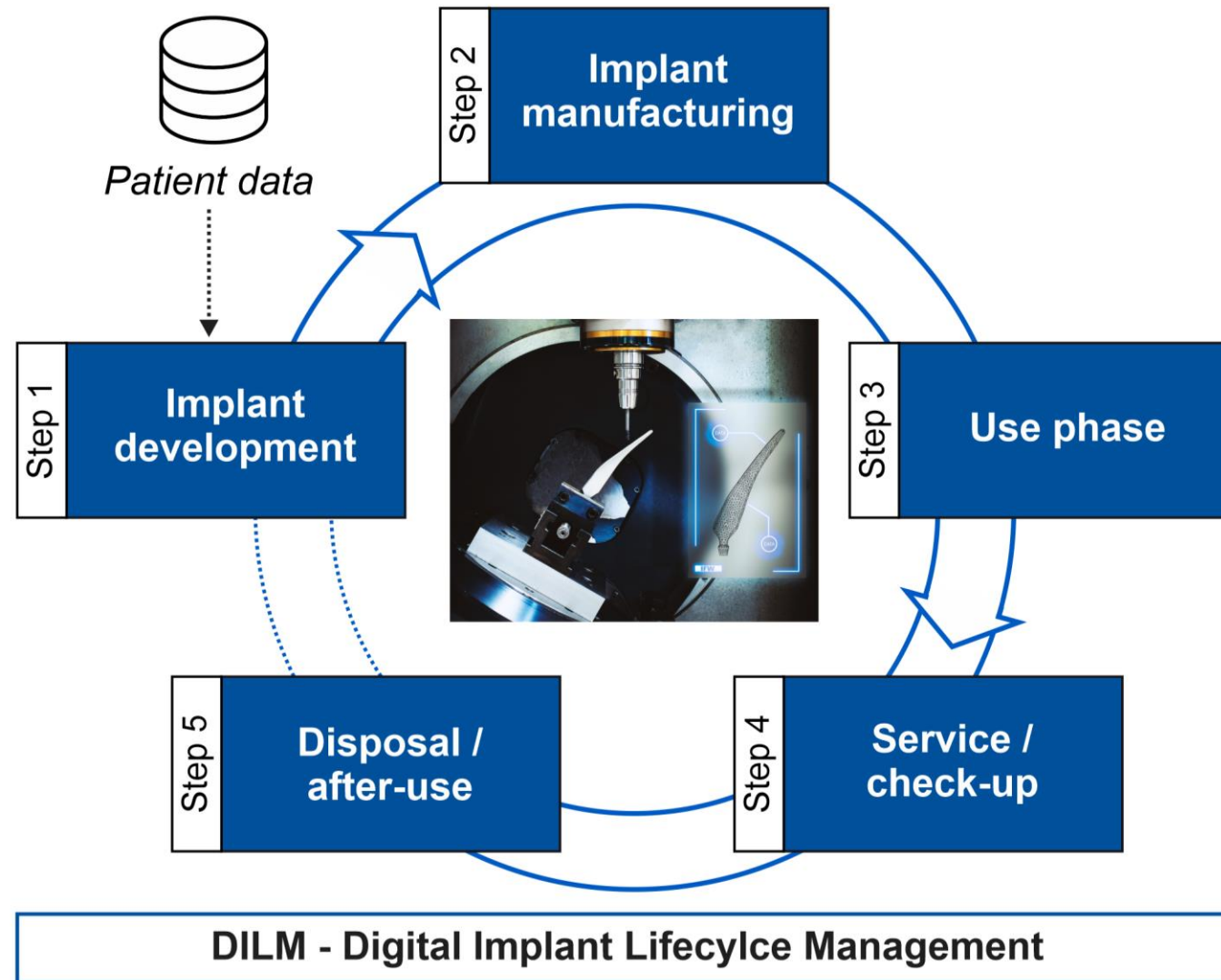
Additive Manufacturing – Deposition welding process



Subtractive Manufacturing: Recontouring

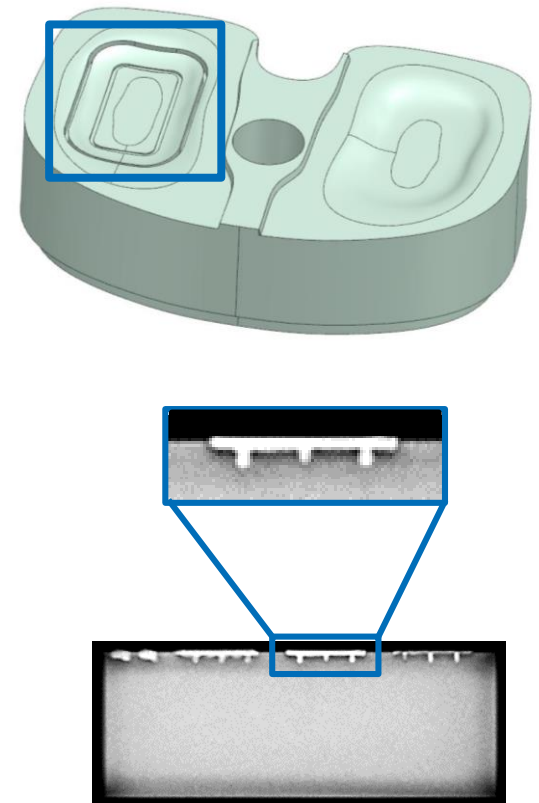
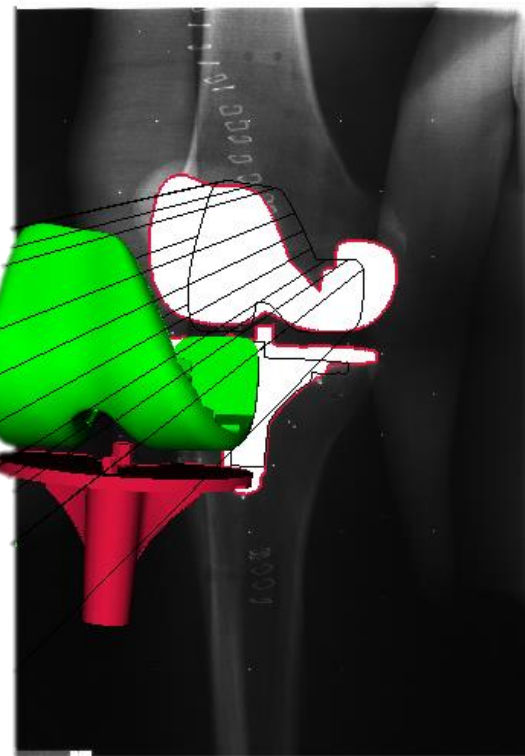
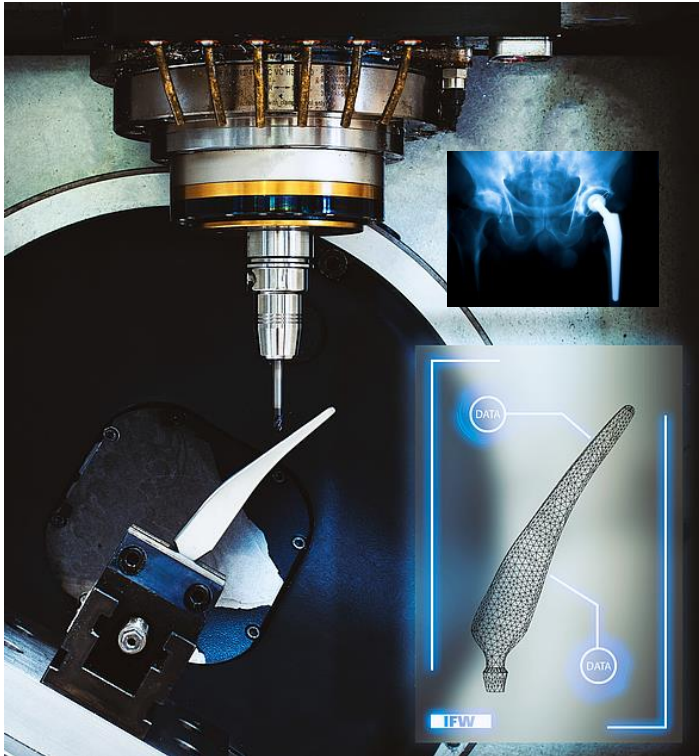


Digital Implant Lifecycle Management



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Open question for the discussion: How can data formats be combined?



Feeding, processing and simulation of data into the Digital Twin before, during and after the use of the implant helps to improve manufacturing, monitoring and patient well-being.

Software Engineering for CPPS

Challenges in production technology

General trends

- Economical production in high-wage countries
- Flexible but also highly automated production systems
- Variations in machine tools (age, component manufacturers)

Challenges regarding digitalization

- Interfaces between different software systems
- Data management (type and location of storage)
- Different data sources and differences in the frequency of data
- Computer scientists must assist with data science

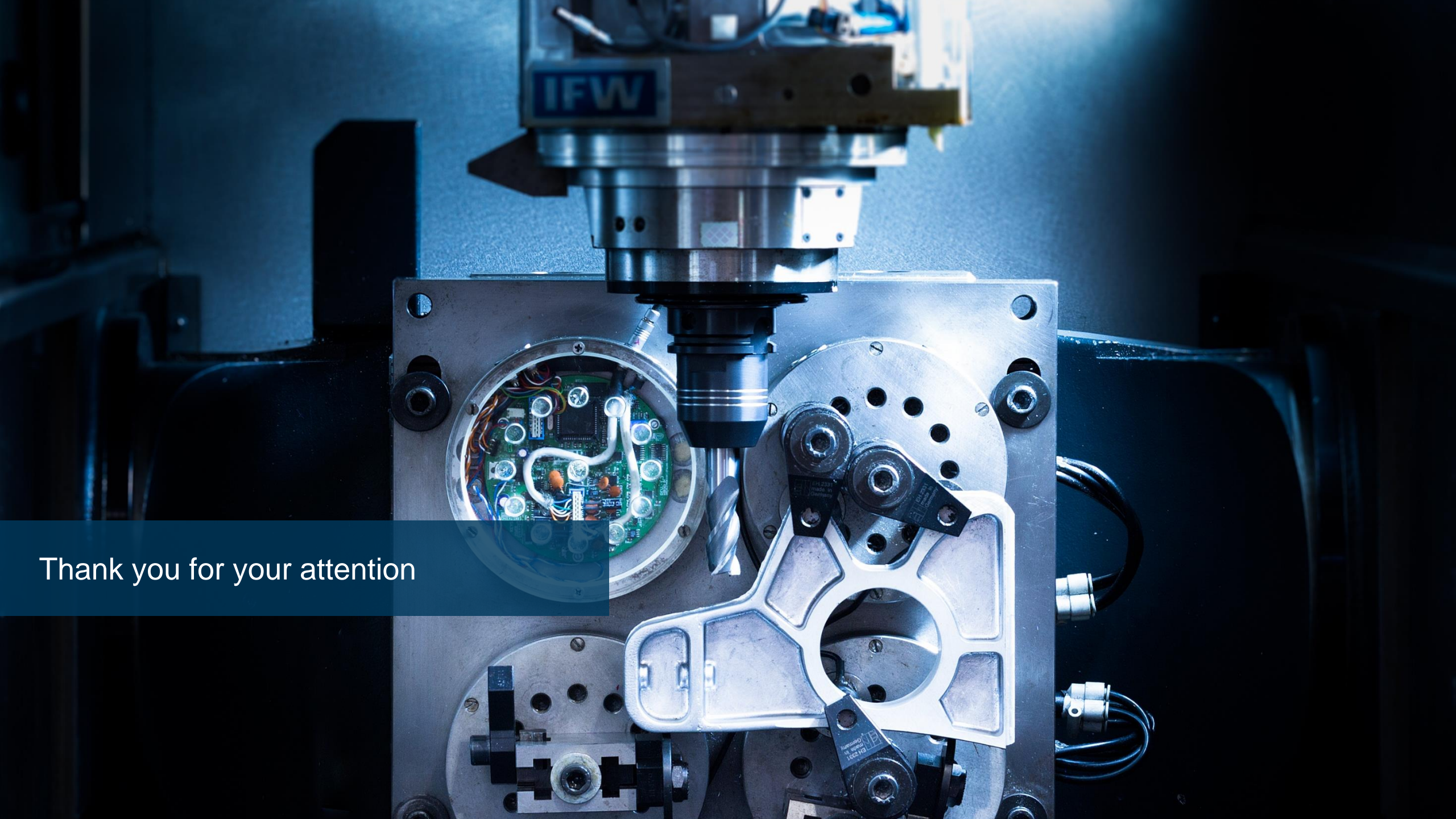


- Software architects (for specific domains)
 - System design → Development of an algorithm
 - Communication of the problem and interface to other departments → Shape shifters

 - Collect requirements (method,...), requirement moderators - neutral interface
 - Detailed program flow chart → Specifications for programming
 - Implementation (technical rough realizers), Keyword: Iterative implementation

 - Prototype development and pre-development
 - VDI guideline 2221
 - Unbiased approach
- What is the requirement for a CPPS?





Thank you for your attention



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