Cloud Based Manufacturing and In-machining Process Quality Control and Feedback

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Sandvik Coromant by the numbers

2500
New products annually to all customers in all our markets at the exact same time

150
Countries represented in

2x
The R&D investments of the industry average

8300
Employees globally

48000
Sandvik Group Employees globally
Significant sources of waste

Pre-machining productivity
Lacking ability to optimize design due to poor input data quality

In-machining and system utilization
<50% utilization of individual machines

Energy flow through machinery
Only 1/3 of energy used for actual forming of manufactured parts,

Degree of automation
Key intelligence captured in experienced industrial practitioners, who cannot process data as effectively as algorithms

Traceability
Only a fraction of data recorded – and even if recorded, even less analyzed and used for improvement and prediction

Significant opportunity to reduce capital intensity and OPEX of the metal based manufacturing industry

Source: Expert interviews, customer benchmarks
People, machines and systems will be much more integrated

**BUSINESS SYSTEMS**
- ERP-System
- PLM Engineering System

**COLLABORATIVE PRODUCTIVITY**
- Human/Human
- Human/Machine
- Machine/Machine

**IT to ICT**
- Big data
- Storage in the Cloud
- Data mining, safety, security
- Data stream management
- Edge Computing

**SHOP FLOOR**
- Sensor swarms
- IT-Openness
- Cost-efficiency/Profitability
- Sustainability
- Reliability & Availability
- Accessibility
- Traceability

**COOPERATION**
- Business Communication
- Social Communication
Process Reliability & Cost

- Process capability
- Resource availability/cost
- Process stability
- Process predictability and robustness
- Machining strategies
- Operation sequencing
- Fixturing
- Tool path
- Cutting tool and cutting data
- Post processing
- Machining Process

- Production

- Quality
- GD&T
- Surface topography/integrity
- Blank
- Features
- Topology/Geometry

- Component

- Machine Tool
- Kinematics
- Dynamics
- Condition
- Control/CNC
- Spindle torque/power characteristics
- Axis limit
- Process Planning
Today’s Process Planning
Model based but discontinuous prediction of time, cost, collision, ....
Today’s Process Planning

Challenges

- Discontinuous process data, need for semi automatic data transfer
- Lack of feedback loops to process planning on quality
- Quality assurance of data, information and knowledge
- Lack of model based knowledge transfer “easy access to right knowledge in right time”
- Less efficient knowledge sharing and collaboration between distributed teams
- Management of design rationale
- Management of security
Future of Machining

- Asset/Material/Product Logistics
  - Tracking
  - Management
  - Autonomous Control
- Customized Product Solution
- Customized Process
  - Material variations
  - Machine Center Adaption

- Virtual Modeling
- Predictive diagnostics
- In–process monitoring
- Autonomous Adjustment/Control
- Process Learning and diagnostics
- Autonomous Quality control & feedback
- Remote Diagnostics/Support
ICT in Machining

Digital manufacturing
Products life cycle management, modeling, design and optimization.

Virtual factories and enterprises
End-to-end integrated ICT allowing for efficiency in networked collaborative value chain.

Smart factories including application experiments of control and sensor-based systems, laser systems and industrial robots.
Machining System Digital Twin
Connecting Virtual & Real time Machining through Digitalization

Augmented reality, a recreation of the physical world

Virtual → Real

The digital twin
CIMLES
Cyber Integrated Metrology, Learning and Evaluation System

Analysis → Evaluation → Learning → Action

Data transfer

Learning state

Pre – Machining
- Physical
- Digital

In – Machining
- Physical
- Digital

Post – Machining
- Physical
- Digital
Process Feed back & Learning

- In-Machining
  - Process monitoring

- Pre-Machining
  - CAD
  - Process planning
  - CAM

- Post-Machining
  - Quality evaluation

- Process feedback
  - Visualization
  - Analysis
  - Learning
CIMLES
Cyber Integrated Metrology, Learning and Evaluation System
CIMLES
Autonomous Machining System
Evaluation & Control
Development towards integrated *pre*-machining, *in*-machining and *post*-machining data for **Blisk Machining Process**
Blisk

Blisks

Cold side
- Fan section

Warm side
- Compressor section
- Combustion section
- Turbine section
Top Entry method for short Blisks

Machine Tool: Hermle C40u – 5 axis
Material: Ti6Al4V

Software
- CAM ConceptsNREC
- Pre-machining optimization: MachPro

Blisk
- Diameter: 968 mm
- Blade height: Max 110 mm
- Number of blades: 48

Segment
- Blade height: Max 110 mm
- Blade width: 100 mm
- Width between blades top: 29.5 mm
- Width between blades bottom: 25.5 mm
Top Entry Method for short Blisks

Complete process for machining; roughing, semi finishing, and finishing

Four levels of milling:

- Depth 1st level 0-16 mm, 2nd level 16-38 mm, 3rd level 38-58 mm, 4th level 58-110 mm

Different tool overhang

Approach: to mill step-wise down each level

Point milling generates a 3D-profile with successive levels of passes

The contact point varies along the radius depending on the desired surface
Product Realization Sequence

Start/input

1. CAD (A1)
   - Operation planning (A2)
     - System: Internal system, Planner, Engineer
     - CAD-models of part, blank, fixture

2. CAM (A3)
   - CAM-part with tool paths in the CAM environment, Cutting tools
   - CAM-strategy document, Movie of simulation

3. CAM-simulation (A4)
   - CT-data
   - CNC-data
   - System: CAM Engineer

4. CAM-simulation (A5)
   - System: Post-processor Engineer
   - Machining simulation report, Movie of simulation, Simulation model

5. Create machine model (A6)
   - Digital CNC cell
     - Machine
     - Tool
     - Fixture
   - System: CAM, Mach. sim Engineer

6. Machine simulation (A7)
   - System: Mach. sim Engineer

7. Machining (A8)
   - System: CNC, Machine Operator

8. Quality evaluation (A9)
   - System: CMM, Measuring engineer

Quality evaluation document

CAD-models
- Drawings
- GeM
- Surface finish requirement

Machine specification, Information, CAD-models etc., of a parts to be included in the simulation environment
Pre-machining process optimization

1. Chip load
   - Maintain desired feed per tooth despite varying work piece geometry during machining

2. Cutting forces
   - Avoid excessive cutting forces on the tool

3. Moment on spindle bearings
   - Avoid spindle bearing failure due to excessive loading

4. Static tool deflection
   - Control dimensional/form error on the part
   - Avoid tool breakage

5. Surface speed
   - Obtain uniform surface finish
   - Extend tool life
Real-time tool and process monitoring

**Tool**
- Embedded systems
- Communication
- Control
- Interface APIs
- Standards & Policies
- Extract process data from sensors at high frequency and high bandwidth

**Machine**
- Interface CNC (HW/SW)
- Interface to Device Gateway
- Device management
- Extract process data from CNC and sensors at high frequency
- Standards & Policies
Pre-, In- and Post machining optimization

Roughing

CAM – Feed optimization  Chip load optimization  In-process data
Pre-, In- and Post machining optimization

Semi-finishing

- CAM – Feed optimization
- Chip load optimization
- In-process data
Pre-, In- and Post machining optimization

Finishing

- CAM – Feed optimization
- In-process data
- In-process Feed-GOM
- In-process cutting forces
- In-process Acc-GOM
- Post-process GOM
Inspection Free Blisk Machining

CAD

CAM

CNC

Machine

Tool

Metrology
Sensors
Need to get as good data about the cutting process as possible

Data
Leverage data from different sources e.g. machine tool and tapping tool

Analytic Approach
Find relations between the physical world and the data we can use

Empirical Model
Applying signal processing and machine learning to build models using collected data
Conclusions

- A large amount of data, information and knowledge are involved in the process planning, machining and quality evaluation activities, which indicate need for proper and efficient ICT-support tools for advanced analysis and understanding.

- A conceptual model and framework for Cyber Integrated Metrology, Learning and Evaluation System (CIMLES) has been proposed and demonstrated.

- Demonstrators for stepwise implementation of CIMLES have been developed and proofed the functionality in selected sub systems.

- The concept need to be further validated and explored including various applications in real industrial environments in order to validate functionality, usability, and efficiency.