Technologies for tool, die and mould making – Today and Tomorrow

Uddeholm Automotive Tooling Seminar 2008
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Fraunhofer-Institute for Production Technology IPT
Aachen, Germany
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Aachen’s Production Management Institutes

RWTH Aachen
- founded 1870
- 30,000 students
- 5,000 students in engineering

Laboratory of Machine Tools and Production Engineering (WZL)
- founded 1906
- 600 employees
  (approx. 160 scientists)

Fraunhofer-Institute for Production Technology (IPT)
- founded 1980
- 340 employees
  (approx. 60 scientists)

WZL Forum GmbH
- in-house training and seminars (e.g. Executive MBA)
Our Topics

The competencies of the institutes in the **tool, die and mold making** field are concentrated in the joint business segment „aachener werkzeug- und formenbau (awf, Aachen tool and die making)“.
**aachener werkzeug- und formenbau (awf) - Overview**

<table>
<thead>
<tr>
<th>Research</th>
<th>Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research for industry partners</td>
<td>Benchmarking</td>
</tr>
<tr>
<td>Co-operative projects:</td>
<td>More than 128 international projects</td>
</tr>
<tr>
<td>Largest EU scientific project in tool, die and mold making: IP EuroTooling 21</td>
<td>Strategic Excellence</td>
</tr>
<tr>
<td>Basic research</td>
<td>Effectiveness and efficient processes</td>
</tr>
<tr>
<td></td>
<td>Technological Excellence</td>
</tr>
<tr>
<td></td>
<td>Optimal use of technologies</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Education</th>
<th>Toolmaker of the year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colloquium</td>
<td>Excellence-in-Production</td>
</tr>
<tr>
<td>Most significant tool makers meeting in Germany: 8th International Conference „Tool and Die making for the Future“, 30.9. / 1.10., 2008 in Aachen</td>
<td>Patron: BDI-Presiden J. Thumann</td>
</tr>
<tr>
<td>Tool Shop Academy:</td>
<td>Most challenging contest for producing enterprises</td>
</tr>
<tr>
<td>In-house training for both management and employees</td>
<td>Up to 300 involved companies per annum</td>
</tr>
</tbody>
</table>
Our Service for Tool Shops

Integrated Benchmarking
...learn from the best!

Strategic Excellence
- Strategy development & implementation
- Market & Competition analyses
- Cost & Lead time reduction
- Global purchase & Tool supply
- Supply Management
- Calculation
- Premium wage

Technological Excellence
- Selection of technology & optimization
- Process chain design
- Automation & Handling
- Simulation & CAD/CAM
- PPS & PDM selection
- Metrology & Quality

Successful in tool making!
Contents

Competence center aachener werkzeug- und formenbau

Excellence in tool and die making

- European tool makers have to differentiate!
- Strategic alternatives through technology
- Measures for future success

Today: Technology use in tool making

Tomorrow: Technological uniqueness

Summary and outlook
European Tool and Die Industry – Under Pressure from China

**Tool design**

<table>
<thead>
<tr>
<th></th>
<th>Work time*</th>
<th>Personnel costs*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>1.714 h</td>
<td>66.160 €</td>
</tr>
<tr>
<td>China</td>
<td>2.471 h</td>
<td>5.875 €</td>
</tr>
</tbody>
</table>

* +44%  
-91%  

**Tool production**

<table>
<thead>
<tr>
<th></th>
<th>Work time*</th>
<th>Personnel costs*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>1.915 h</td>
<td>58.407 €</td>
</tr>
<tr>
<td>China</td>
<td>3.083 h</td>
<td>4.801 €</td>
</tr>
</tbody>
</table>

* +61%  
-91%  

*) Ø annual average

Source: WZL study „Tooling in China – Chance or Threat?“
Differentiation through technological uniqueness

Extension of the business model by introducing additional services to the customer such as availability, short lead times etc.

Price competition → Added value through increased customer’s benefit → Technological uniqueness

Technological uniqueness:
- reduces competition in a globalised market environment
- offers new possibilities to the customers
- enhances the added value for the company
Technological process chain has a huge »indirect influence« on lead time and costs

- In this period, only the tool maker is responsible for Time-to-Market!
- **Only necessary work** related to complex geometries shall be performed here
- All other parts of the tool can be **standardised** and manufactured before
  - Frames, Pre-machining, Hardening, Cooling channels, ...
- **Need for high performance processes** for hard machining with highest precision

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**Selected case studies – relevant to create uniqueness!**

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Description</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS1</td>
<td>Moulds for advanced injection moulded parts</td>
<td>New mould architecture for injection-moulded interior car door panels</td>
</tr>
<tr>
<td>CS2</td>
<td>Tools for precision and micro tooling</td>
<td>Optical lens system produced by plastic injection moulding and precision glass pressing</td>
</tr>
<tr>
<td>CS3</td>
<td>Moulds for small batches of high variety IM products</td>
<td>Toolboth machine cover</td>
</tr>
</tbody>
</table>
## Contents

- Competence center *aachener werkzeug- und formenbau*
- Excellence in tool and die making
- **Today: Technology use in tool making**
  - Technological comparability of different branches
  - Technologies worldwide
  - IT and NC process chains
- **Tomorrow: Technological uniqueness**
- Summary and outlook
Mold and die types and technology use

**Injection molding and die casting**
- Specific attributes:
  - Surface
  - Accuracy
  - Filigree parts
- Machining operation:
  - Milling
  - Turning
  - Grinding
  - Sinker EDM
  - Wire EDM
- Importance:

**Massive forming**
- Specific attributes:
  - Material (temperature)
  - Surface zone
  - Accuracy
- Machining operation:
  - Milling
  - Turning
  - Grinding
  - Sinker EDM
  - Wire EDM
- Importance:

**Deep-drawing**
- Specific attributes:
  - Surface
  - Accuracy
  - Geometry
- Machining operation:
  - Milling
  - Turning
  - Grinding
  - Sinker EDM
  - Wire EDM
- Importance:

**Punching und Bending**
- Specific attributes:
  - Material
  - Accuracy
  - Surface
- Machining operation:
  - Milling
  - Turning
  - Grinding
  - Sinker EDM
  - Wire EDM
- Importance:

**Focus machining of freeform surfaces**

**Prismatic components of tools**
Technological change of the mold and die making industry (mainly valid for free form surface machining)

- Copy milling
- Eroding with copper electrodes
- CNC-machining
- Increasing share of milling
- Eroding with graphit electrodes
- HSC milling
- Presetting of work pieces
- Handling system
- Hard machining
- Automated process combination
- 5-axis-simultaneous-milling

Productivity/ economic efficiency

Grade of development
Employment of Machinery in the Mold and Die Industry
A comparative study of selected countries

- A total of 164 interviews
- Contacts to associations and universities
- Analysis of literary sources
## Typical factory equipment in the mold and die making industry - International comparision

<table>
<thead>
<tr>
<th>Portion of productive machines</th>
<th>HSC 5 axis milling</th>
<th>HSC milling</th>
<th>Machining center</th>
<th>NC-machines »white«</th>
<th>NC-machines »green«</th>
<th>Manual machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
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<td>Middle</td>
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<table>
<thead>
<tr>
<th>Country</th>
<th>HSC 5 axis milling</th>
<th>HSC milling</th>
<th>Machining center</th>
<th>NC-machines »white«</th>
<th>NC-machines »green«</th>
<th>Manual machines</th>
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<tbody>
<tr>
<td>USA</td>
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<td>Brazil</td>
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<td>Germany</td>
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<td>Italy</td>
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<td>Czech Republic</td>
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<td>China</td>
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<tr>
<td>Korea</td>
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<td>Taiwan</td>
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=> Increasing importance of 5-axis- and HSC machines
Importance of the CAx-process chain in mold and die making

Substantial steps for mold and die making:

- Design of CAD model
- NC-programming
- Machining
- Assembly

Possible steps to generate NC-programs:

- Optimizing of the CAD models
- CAM programming
- Simulation of the tool paths in CAM
- Post processing
- NC-code optimizing
- NC-code simulation
- Implementation of programs on the machine

- closing of surface areas
- burnishing of transitions
- milling strategies
- tool selection
- tool path calculation
- process parameters
- tool collision
- removal performance
- theoretical processing time
- translation of CAM-codes in NC-codes
- target: optimized machine behaviour
- collision control
- machine behaviour
- real processing time
- adjustment of program headers
- start up of cutting tools

Perception of CAx-chain

- Mold and die makers predominantly deal with construction, machining and assembling of tools
- Programming of NC programs often has small share of the whole process chain (Estimation: 5-10%)
- Only few mold and die makers perceive the potentials of optimisation in NC-programming.
- The relevance of individual process steps is not universal. An isolated observation is always necessary.
Contents

Competence center aachener werkzeug- und formenbau

Excellence in tool and die making

Today: Technology use in tool making

Tomorrow: Technological uniqueness

- High precision five axis hard milling
- Ceramic form inserts for sheet metal forming
- Laser structuring of surfaces

Summary and outlook
Technological competencies in entrepreneurial environment

Technological competencies

Technological needs

- „Needs are exceeding abilities“
- Low cost, low quality

Technology leader

- „Abilities are exceeding needs“

Positioning of single technologies

Process ability

- Need for investment
- Process with potential for external sourcing

Machine tool ability

- High competence
- Process optimisation potential

- Positioning the company in consistence with the own technological abilities

- Focus on core competencies and continuous innovation in these fields
NC-Milling in tool making – former perspective

100 % of total machining effort

3-axis-milling
(Roughing/Finishing)

3- axis HSC
(Finishing)

Simultaneous 5-axis

100 % CNC-Penetration

Copy Milling

% of total machining effort:

75

50

25

NC-Milling in tool making – perspective ten years later

100 % of total machining effort

Copy Milling

3-axis-milling (Roughing/Finishing)

3-axis HSC (Finishing)

Simultaneous 5-axis

Sim. 5-axis HSC

Simultaneous 5-axis machining
Advantages for tool making?

Obstacles for the introduction of simultaneous 5-axis machining

- HSC-machining provides capable approaches for most of the machining tasks
- High effort of CAM- programming
- Limited availability of capable CAM- modules
- Complex NC-process chain impairs process stability

Lessons learned in aerospace industry

- Keeping tools under constant engagement conditions creates reliability even under extreme conditions
- Exceeding existing limits!

Simultaneous 5-axis machining is successfully applied by the aerospace industry

These developments should be transferred to the tool- and die making industry
»HardPrecision«
High precision five axis hard milling

Targets
- Optimization of the milling process for complex geometries in high hard tool steel up to 68 HRC
- Focus on complex five axis milling
- Integration of the whole process chain for hard milling

Procedure
- Further development of a fully hydrostatic milling machine
- Optimization of the milling tool and coating technology as well as peripheral systems
- Development of novel milling tool concepts and milling strategies following technological requirements

Results
- Drastic reduction of programming and machining times and shortening of process chains
- Ameliorated milling tool life time and part quality ($R_a < 0.2 \, \mu m$; Deviations $< 5 \, \mu m$)

Project information
- Funded by the European Commission
- 12/05 until 12/07
»HardPrecision«
Holistic system optimization to reliably run process at its limit

- CAM and NC strategies
- In-machine measurement
- AE process monitoring
- Machine tool design
- Damped workpiece holder
- Milling tools and coatings
- Process technology
- Economical evaluation

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Advanced process layout needs advanced tool path design!

NC data analysis and optimization: **NC-Profiler**

- Software for NC-data analysis and optimization
- B-Spline-module based on G01-programs
- open XML-format for the definition of kinematics, process, and NC-parameters
- Analysis functions, graph plot, 3D-plot
- 3D-plot: tool path, measuring of point distance, referencing with NC-sets
- Post Processing and NC-data-conversion

NCProfiler Copyright © 1999-2006 Fraunhofer IPT
»HardPrecision«

Potential of optimized tool path in roughing – circular roughing

Material
- 1.2379
- S 6-5-2
- S 6-5-3 PM

Conventional

Material

Machined volume [cm³]

240 µm land wear VB

Circular
»HardPrecision«

CBN for hard machining of complex moulds

Material
Böhler S600 (S 6-5-2)
64,3 HRC

Tool
Seco Tools; CBN200
D = 16 mm; R = 4 mm

Parameters

- \( a_e = 4 \text{ mm} \)
- \( a_p = 0,1 \text{ mm} \)
- \( v_c = 150 \text{ m/min} \)
- \( f_z = 0,1 \text{ mm} \)

<table>
<thead>
<tr>
<th>Tool life [mm]</th>
<th>3000</th>
<th>6000</th>
<th>9000</th>
<th>12000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coated carbide</td>
<td>120 ( \mu \text{m} )</td>
<td>90 ( \mu \text{m} )</td>
<td>60 ( \mu \text{m} )</td>
<td>30 ( \mu \text{m} )</td>
</tr>
</tbody>
</table>

0,4 \( \mu \text{m} \) roughness \( R_a \)

- Without edge rounding: 0,3 cm
- With edge rounding: 0,2 cm
- Without edge rounding: 0,1 cm
- With edge rounding: 0 cm

Material

- Coated carbide
  - Without edge rounding
  - With edge rounding (ca. \( r_c = 20 \mu \text{m} \))

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»Keraform«
Freeform ceramic inserts for deep drawing of hard to form materials

Motivation
- Coating of tools mostly not feasible
- Significant increase of tool life by the use of Silicon Nitride Ceramic
- No lubricants due to favourable tribological properties

Objective
- Qualification of freeform ceramic inserts for economic deep drawing of advanced sheet metals

Approach
- Adapted tool design
- Optimized joining concepts for ceramic inserts
- Developing of process chain for insert production based on jig grinding, US-assisted grinding as well as laser-assisted milling
- Economical evaluation

Quelle: IFUM
»Keraform«

Process chain for 5-axis grinding of ceramic inserts

Parameters

Machining strategy

High surface finish and form accuracy

High removal rates

5-axis machining

CAD/CAM NC

Machining strategy

Parameters
»FlexOStruk«
Flexible and Near Net Shape 3D Laser Beam Structuring

Initial situation in the automotive industry:

- Increasing demand for surfaces with haptic or optical properties
- At present fabrication of dies through chemical etching or leather lined models and galvanic casting
  - Low flexibility
  - High time and costs efforts

<table>
<thead>
<tr>
<th>3D Structure Design</th>
<th>Injection Mold or 3D-Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Reference Structure</td>
<td>CAD-based Structure</td>
</tr>
<tr>
<td>3D Part (Free-Form Surface)</td>
<td></td>
</tr>
</tbody>
</table>

Digital Structure Mapping
Deformation free mapping of the structures on the surface (part specifical adjustments possible)

NC Data Generation
Full generation of process parameters by CAD/CAM-technology; laser modul control by NCProfiller

Manufacturing Process
full automated 3D laser beam structuring

Structured Product

Quality Control
direct control of the tool quality in the machine
5+3-Axis Laser Structuring Machine and First Test Samples (molds)

Highlights of the machine
- 3-axis laser system modular integrated into a 5-axis HSC milling machine: manufacturing in one clamping
- NC-data in ISO-NC-code, using normal CAM-software
- main control unit is Heidenhain iTNC 530 motion control linked with special software modul (NCProfiler)
- high ablation rate and surface quality by short pulsed laser
- wide material range: steel, alu, ceramics, glass and plastic

»FlexOStruk«-Machine

Regular structure

Synthetic loop structure

Irregular structure

Natural leather grain
»FlexOStruk«
Application: Designed plastic surfaces of freeform interior parts

Application

Synthetic 3D structures
Free form surface
Part optimisation
Reduced structure height

First test parts successfully injected

Source: IED University Essen

Source: Fraunhofer IPT
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**Summary and outlook**
- Differentiation through technological uniqueness
- …it is still worth to start tooling business in Europe!
Technology is one key success factor in future tooling business in high wage countries!

- Tool making shifts from handcraft to industrial manufacturing
- Manufacturing technologies are developing fast
- Tool makers can differentiate through unique and focussed technology application

➔ Technological uniqueness supports you in being a succesful toolmaker!
... it is still worth to start tooling business!

**Spheres and aspheres**
- Convex/concave
- Diameter 0.5-80 mm
- Num. aperture <0.9
- Accuracy >l/6 (@λ632 nm, 15 nm RMS)
- Radius accuracy >1-2 μm
- Surface finish >2 nm RMS

**Cylinder lenses**
- Single lenses / arrays
- Length <100 mm
- Opt. aperture <0.85
- Accuracy >l (@λ632 nm)
- Surface finish >10 nm RMS

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Thank you for your attention!

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