Production Technology Center Berlin

Introduction to the Fraunhofer IPK

Industrialization of CLIC and X-band structures

CLIC Workshop 2015

26 – 30 January 2015
CERN

Dr.-Ing. Dirk Oberschmidt

Fraunhofer IPK
INSTITUTE
PRODUCTION SYSTEMS AND
DESIGN TECHNOLOGY

IWF
INSTITUTE FOR MACHINE TOOLS
AND FACTORY MANAGEMENT
TECHNISCHE UNIVERSITÄT BERLIN

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Mission and Goals

Innovations
for Industry

- Fundamental research and education as well as applied research and development
- Optimization of industrial processes – from the product idea through to product development, design and manufacture
- Fast transfer of R&D results into practical applications
- Cost-effective and environmentally friendly solutions for SME

Production Technology Center

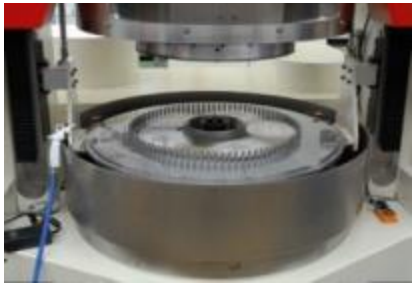
Facts and Figures

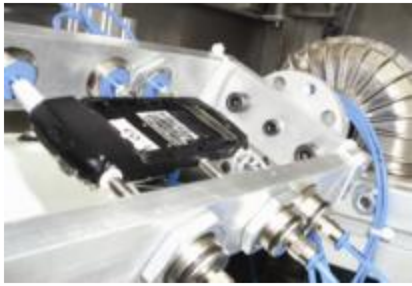
- 1986 IWF and IPK move into PTZ
- > 580 employees
- More than 90 test areas and 9 special laboratories on about 15 000 m²
- Budget of 29 Mio. Euro in 2013
- Spin-offs and start-ups by 12 % of former staff members

Markets and Customers

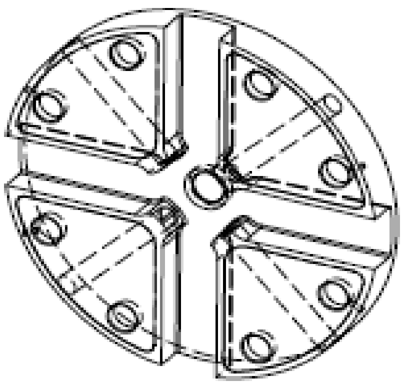
Our innovative technologies strengthen your competitive position

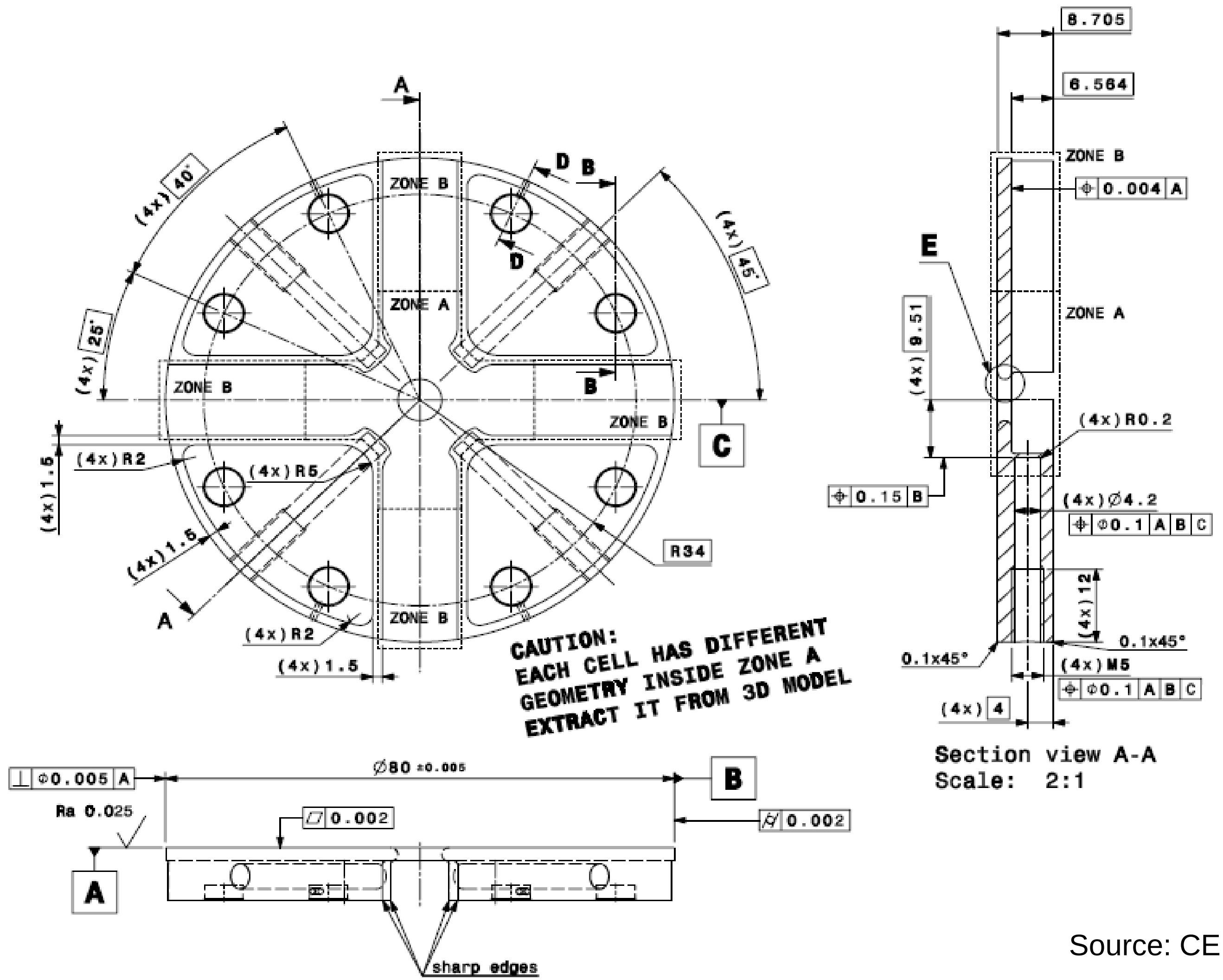
- Mechanical and plant engineering
- Tool and mould making
- Vehicle construction
- Electrical engineering
- Software applications
- Health care
- Public institutions





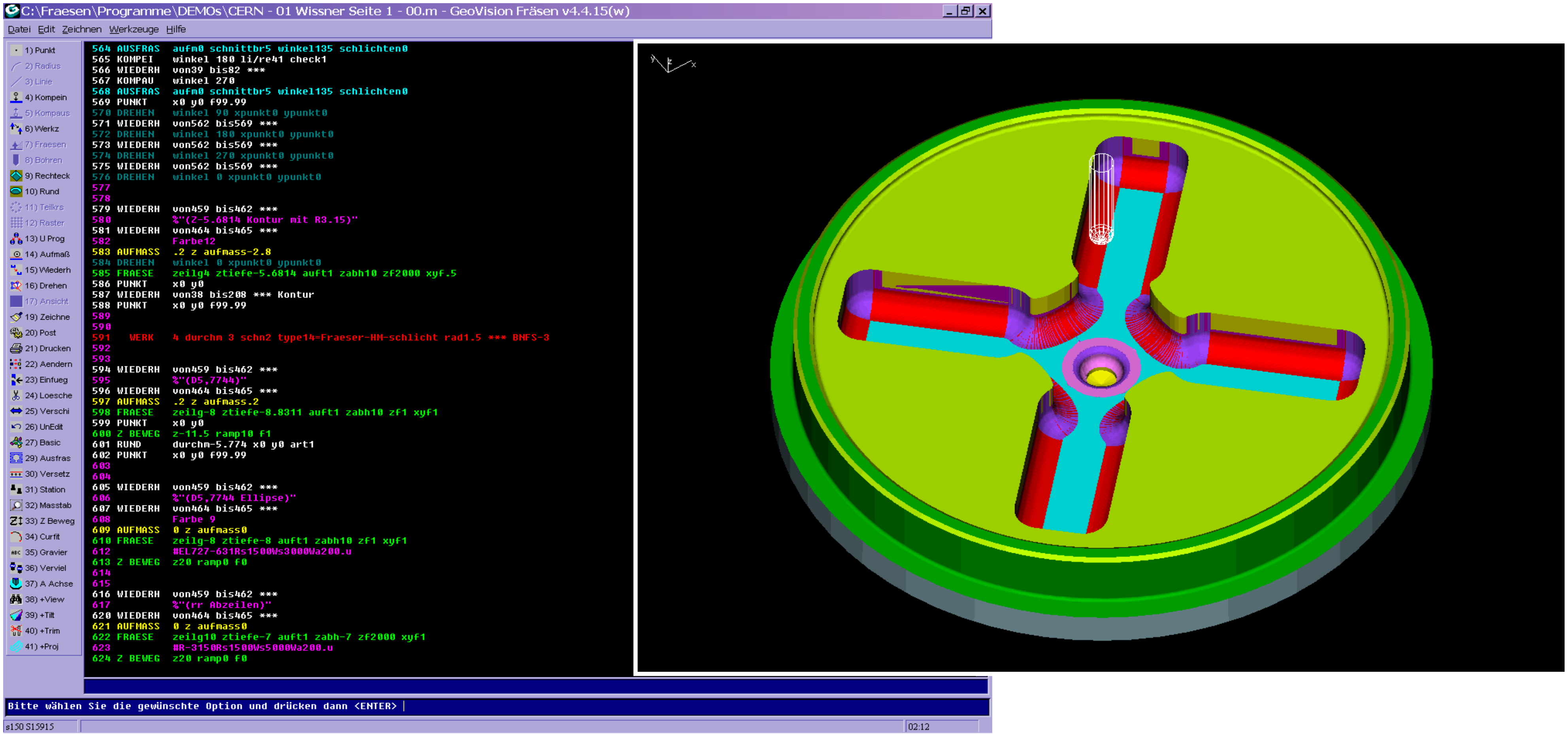
Feasibility Study Accelerator Disc





Source: CERN

NC-programming – Resolution, Multi-Axes Functionality, and Strategy Depending on Used Software



Production Planning: Manufacturing and Measurement

Work steps:

Complete machining in one work step

- Drill holes
- Threads

Complete machining in several work steps

- Flat surfaces
- Cylindrical surface (circumference)
- Cavities
- Side walls
- Inner radii

Specialities:

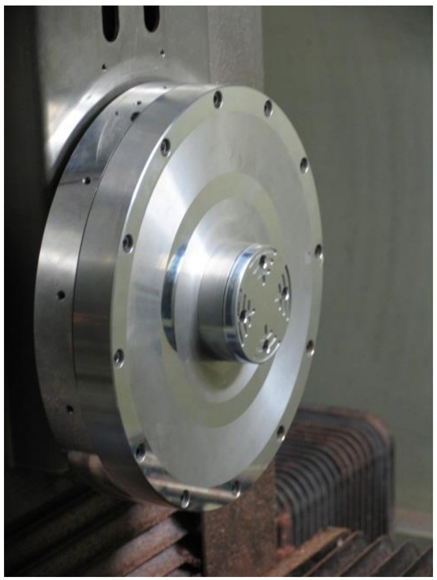
- High precise clamping systems
- Heat treatment
- Frequent measurement of specific features

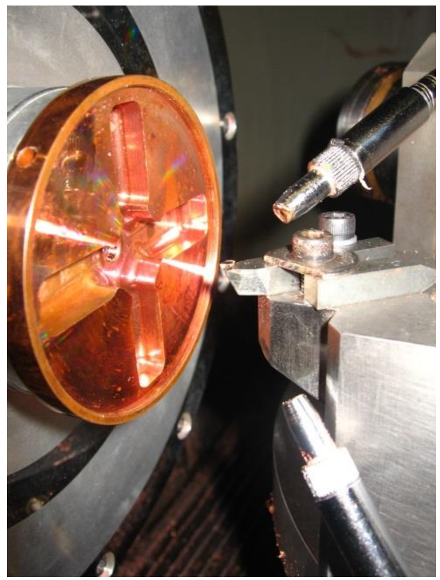
High Precision Milling

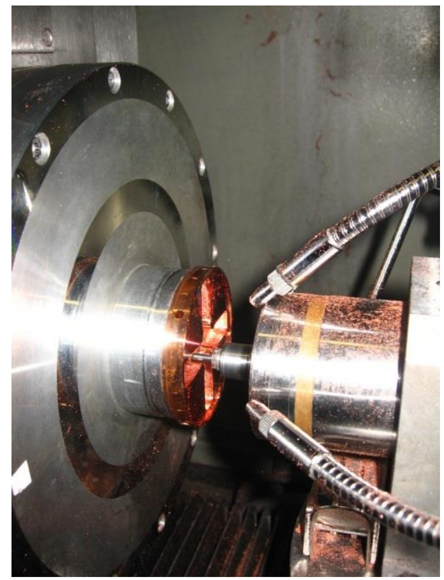
- Carbide end mills
  (D_{min} = 0,3 mm; n_{max} = 100.000 min^{-1})
- Workpiece setup by 3D-tactile probe
- Tool setup by laser-system
- System3R zero-point clamping system
  (positioning accuracy +/- 2 µm)

Ultra Precision Cutting

- Diamond turning and milling tools (D_{min} = 3 mm; n_{max} = 75.000 min^{-1})
- Vacuum-chuck for workpiece (manual positioning)
- Potential automation
  - Automatic workpiece positioning based on sensors for runout and unbalance
  - Automatic tool setup system based on optical relativ-measurement system

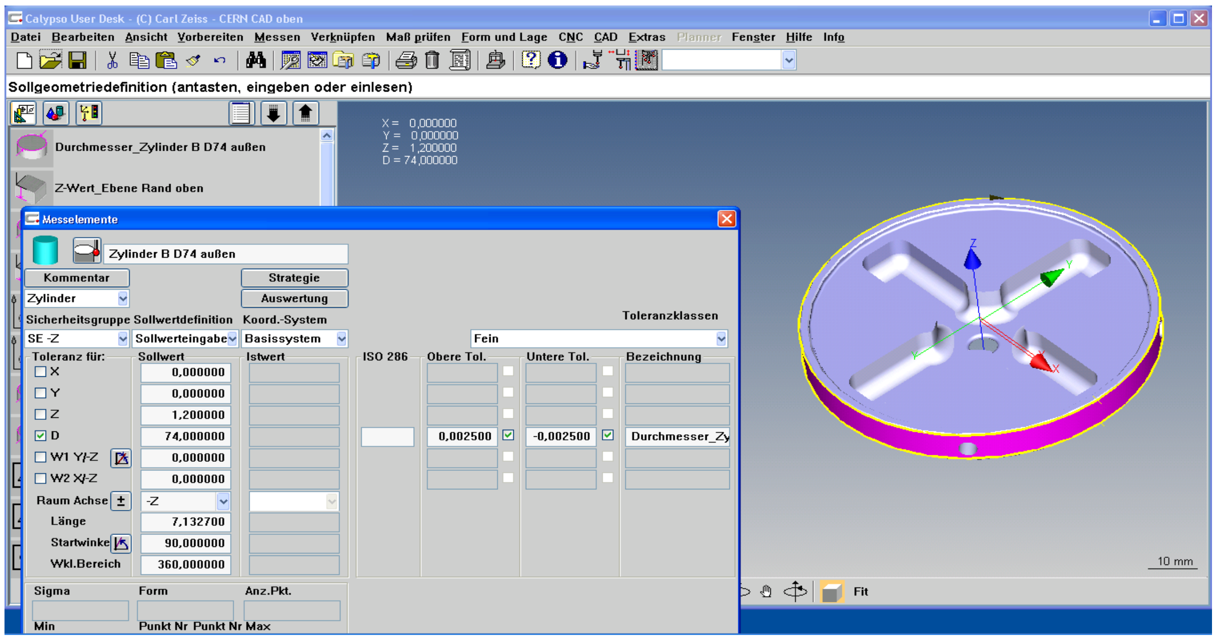




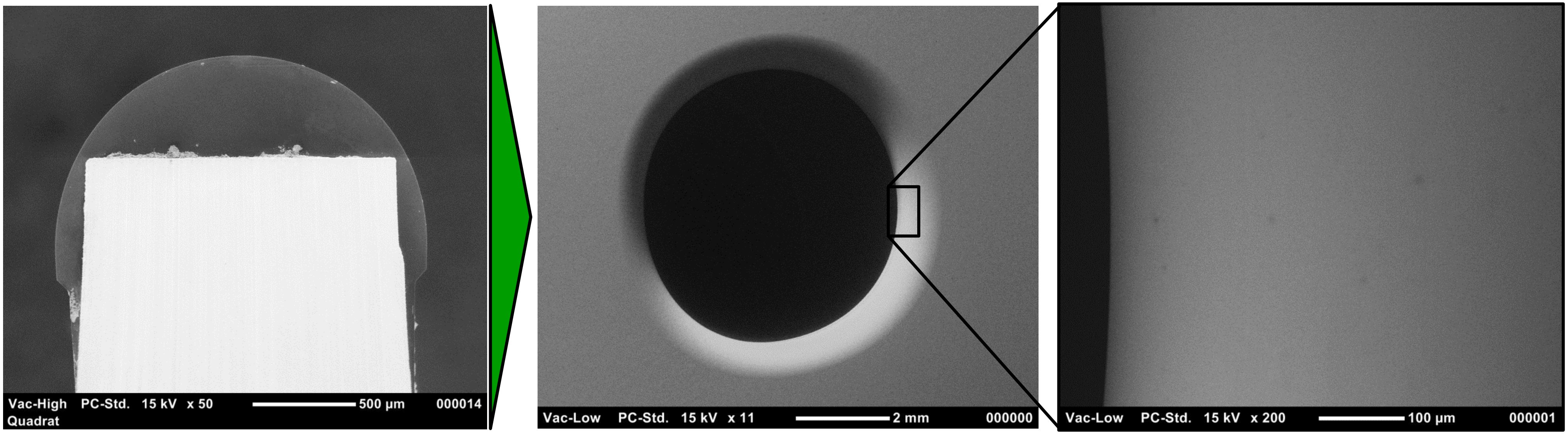


Measures for Quality Control

- Tool measurement before and during work step
- Workpiece measurement before and after work step
- Control of environmental conditions regarding measurement conditions of CERN



Results Regarding Shape and Roughness – Example Iris



- Specially designed diamond tools
- Flat (milled surface) to iris (turned surface) transition-free

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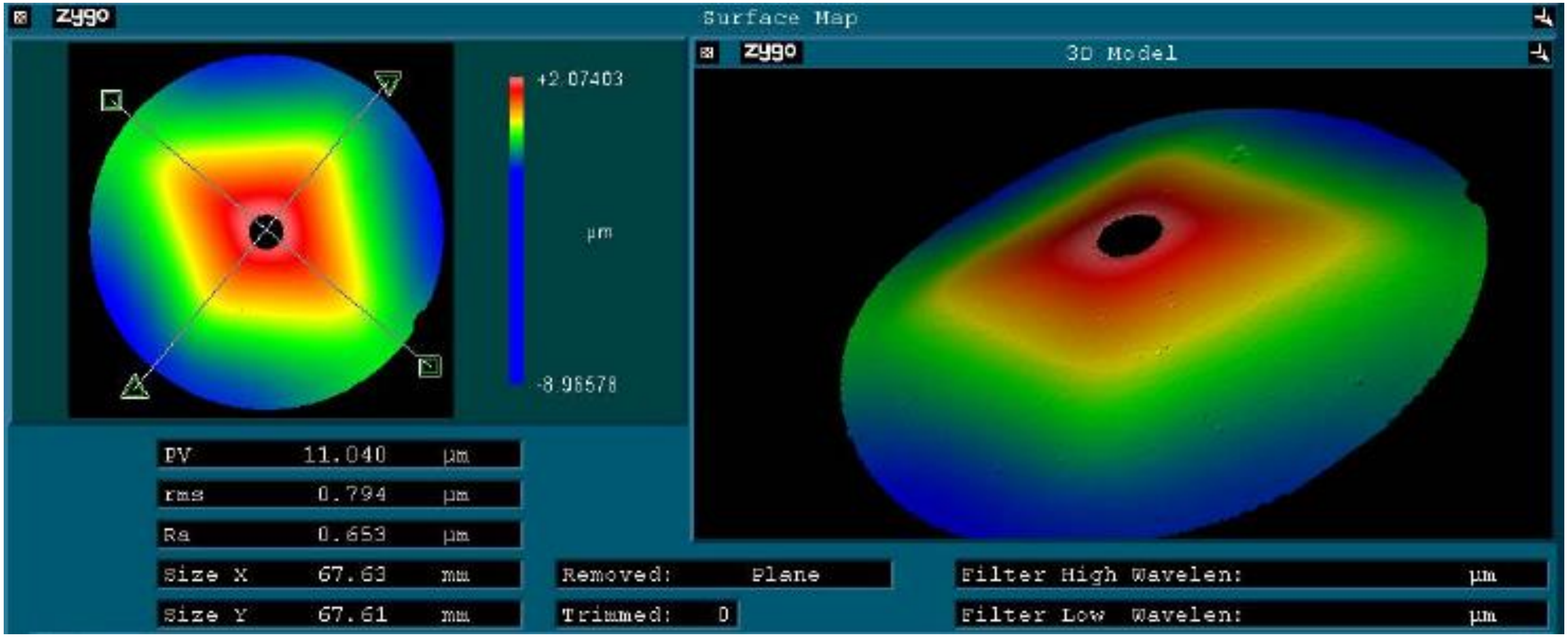
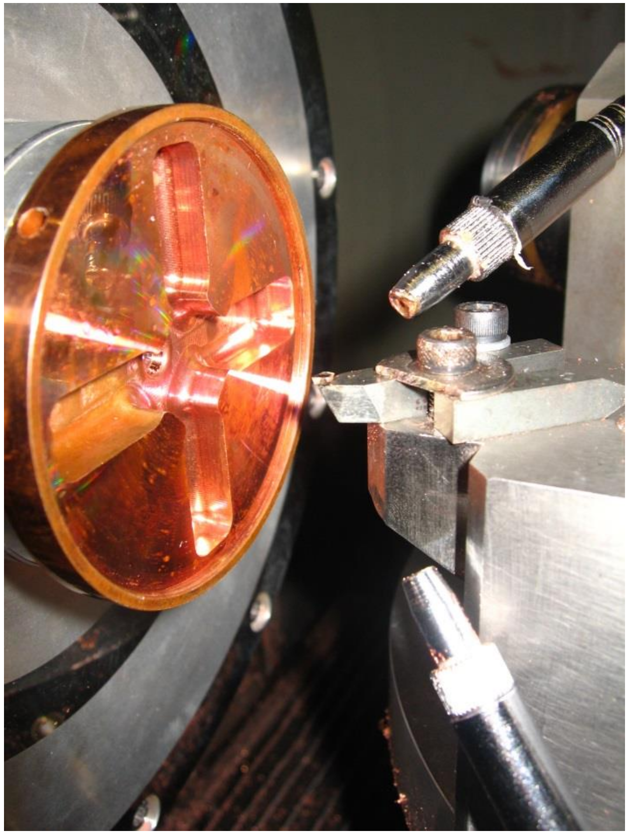
Typical Error – Flatness after Machining



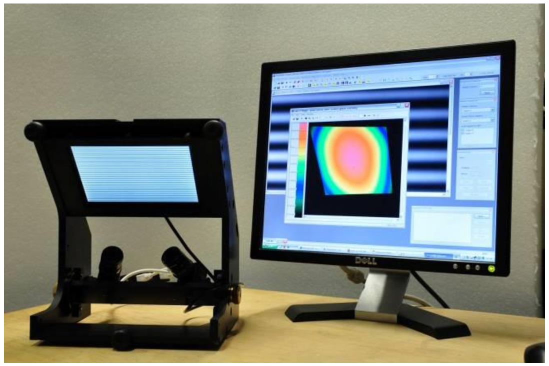
- Machining related stress leads to deformations that follow features
- Flatness measurement in clamping position is (not the best) solution
  - Shape deviation leads to positioning deviations in the stack

Questions from the feasibility study:



- What are solutions that make the disc manufacturing reliable, reproducible, and cheap?
- What are strategies to minimize the risks due to machine tool breakdowns, staff loss, extended delivery time of tools, and other difficulties?
- Is it possible to design processes based on standard procedures?
- Is it possible to use the particular excellence of various manufacturers in a “virtual facility” based on an international network?

Process Optimization - Increase of the Accuracy of Workpieces by Machine Tool Integrated Measurement



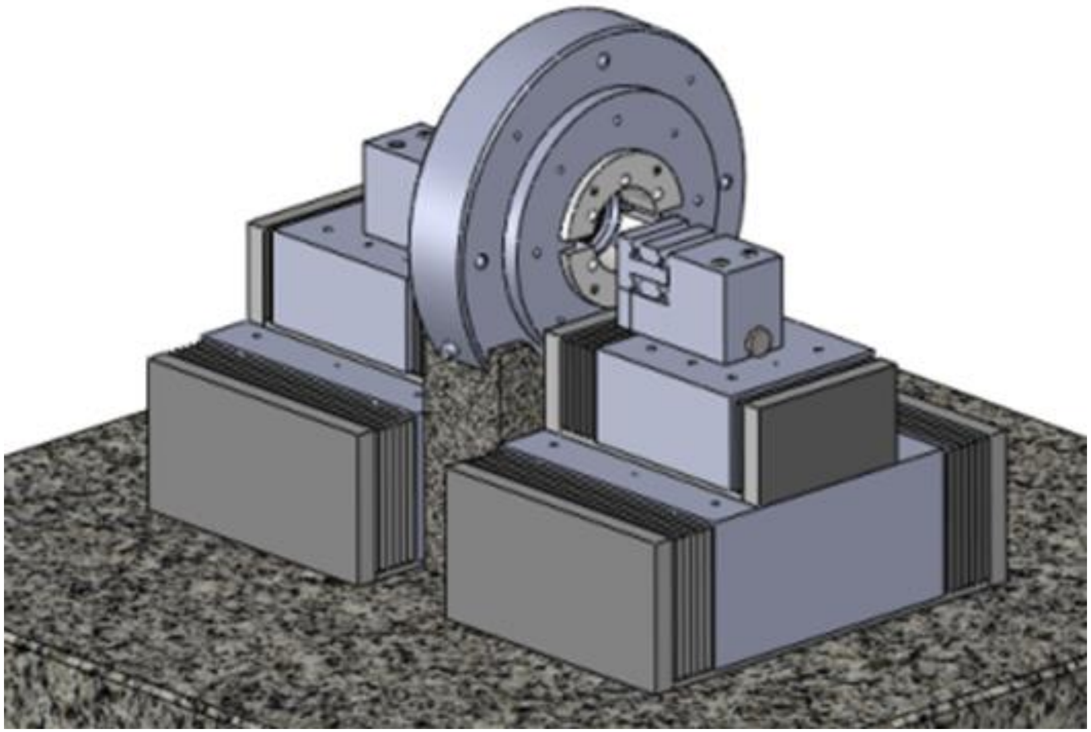
MiniPMD with evaluation screen

Moore Nanotech 350 FG with integrated MiniPMD

Example:

- Machine tool integration of Phase Measuring Deflectometry in an ultra precision machining centre
- Optimization to a so called “MiniPMD”
- Correction cycle for rotationally symmetrical workpieces
- By the correction cycle the shape accuracy could be increased by 65% to 90%, depending on the considered geometry

Innovative Machine Tool Concepts for Two-side Machining

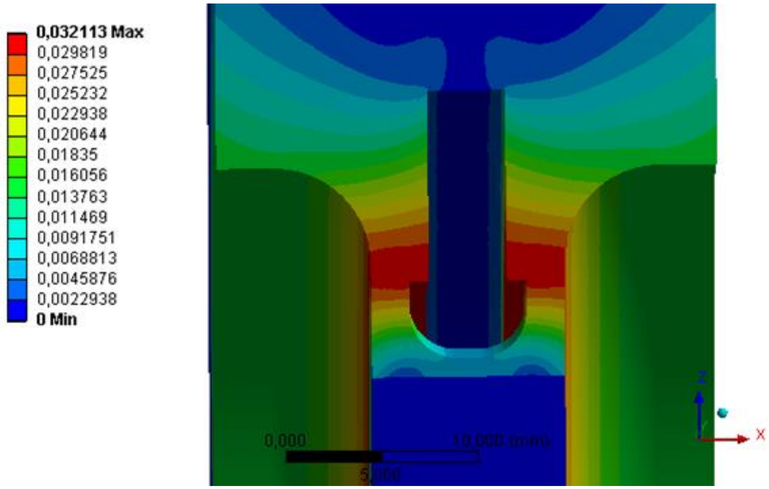


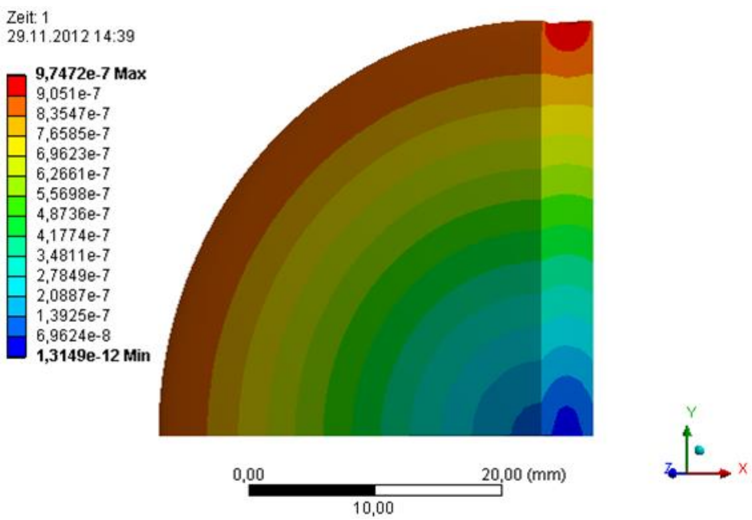
Machine tool concept (PCT patent process in progress)

- Simultanous machining of bottom and top surface
- Ultra precise relative positioning of features on bottom side to top side
- Clamping without influence on shape

Clamping Force in a Two-side Machining System

Deformation /mm



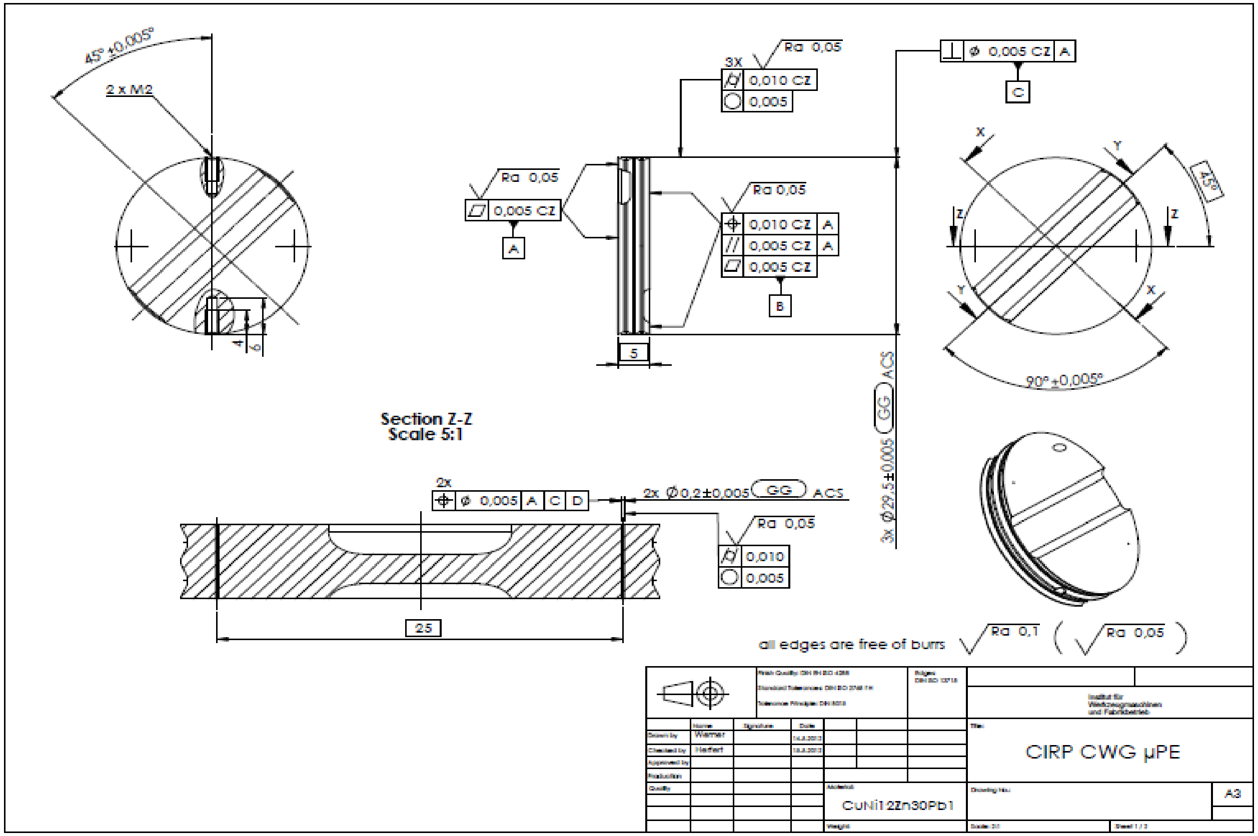


Simulation of clamping force and resulting deformation

- Workpiece material: Germanium
- Diameter d = 70 mm; width b = 10 mm
- Contact pressure pa= 5,61 · 10^{-3} MPa
- Max. deformation on cylindrical surface e_{vc} = 0,9 nm
- Max. deformation on flat surface e_{vf} = 0,9 nm

- diameter d = 70 mm; width b = 4 mm
- Contact pressure pa= 1,68 · 10^{-2} MPa
- Results:
- Max. deformation on cylindrical surface e_{vc} = 2,4 nm
- Max. deformation on flat surface e_{vf} = 2,1 nm

Production in Networks: Evaluation part of the CIRP Collaborative Working Group on Micro Production Engineering



workpiece material: CuNi12Zn30Pb1

Requirements:

- Slightly reduced compared to industrial demands
- Geometrical accuracy 5 µm to 20 µm
- Arithmetical mean deviation Ra = 50 nm
- All values are oriented towards the state-of-the-art results.

The CWG‘s Interlaboratory Comparison

Participants:

- 21 institutions worldwide for manufacturing
- 3 institutions for measurement tasks

Procedure:

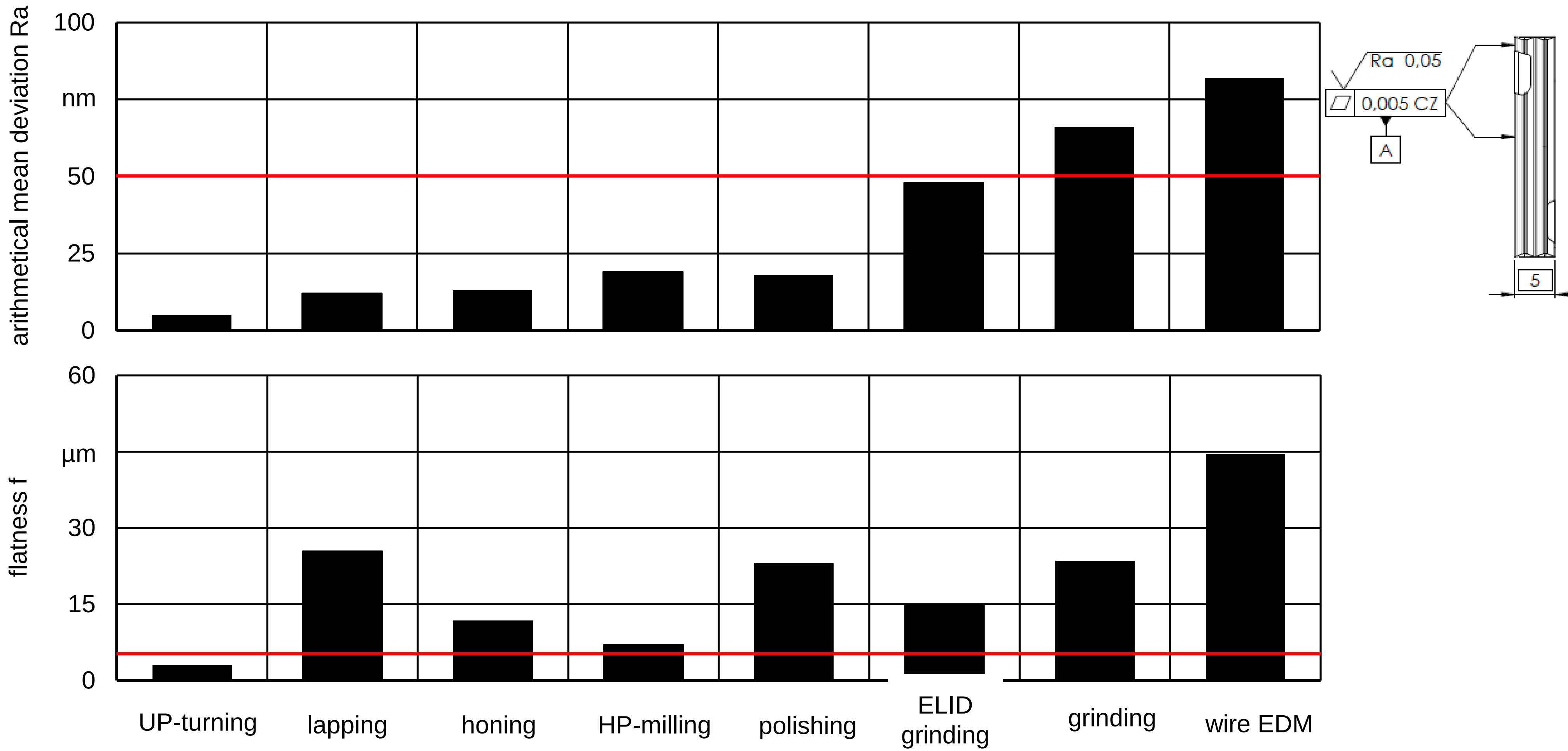
- Investigation of suitable single manufacturing technologies
- Combination of technologies to sequences of production process chains
- Investigation of complete production process chains

Results:

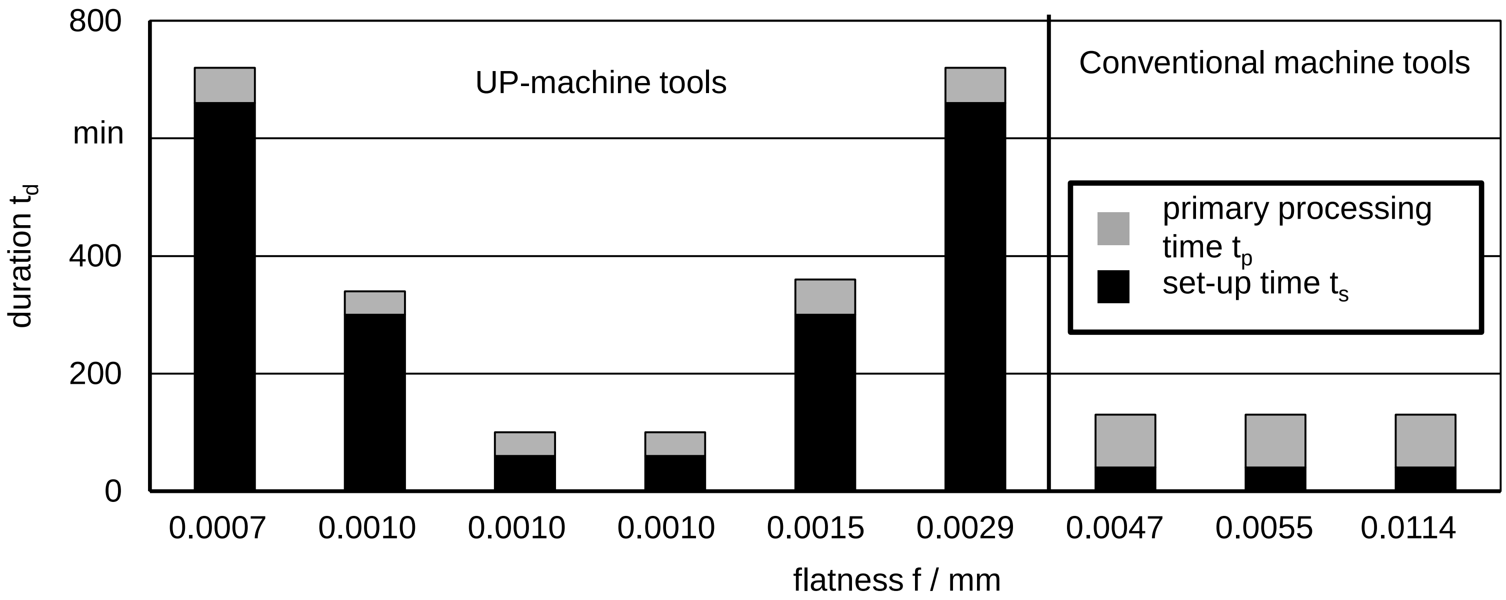
- Will be published in CIRP keynote paper 2016

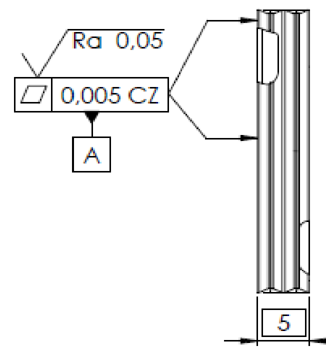
  Uhlmann et. al.: „Process Chains for High-Precision Components with Micro-Scale Features”

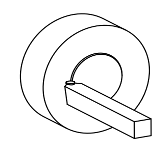
Capability of Manufacturing Processes (trends)
- plane surface -



Influence of Machine Tool and Process Duration
- turning of plane surface -

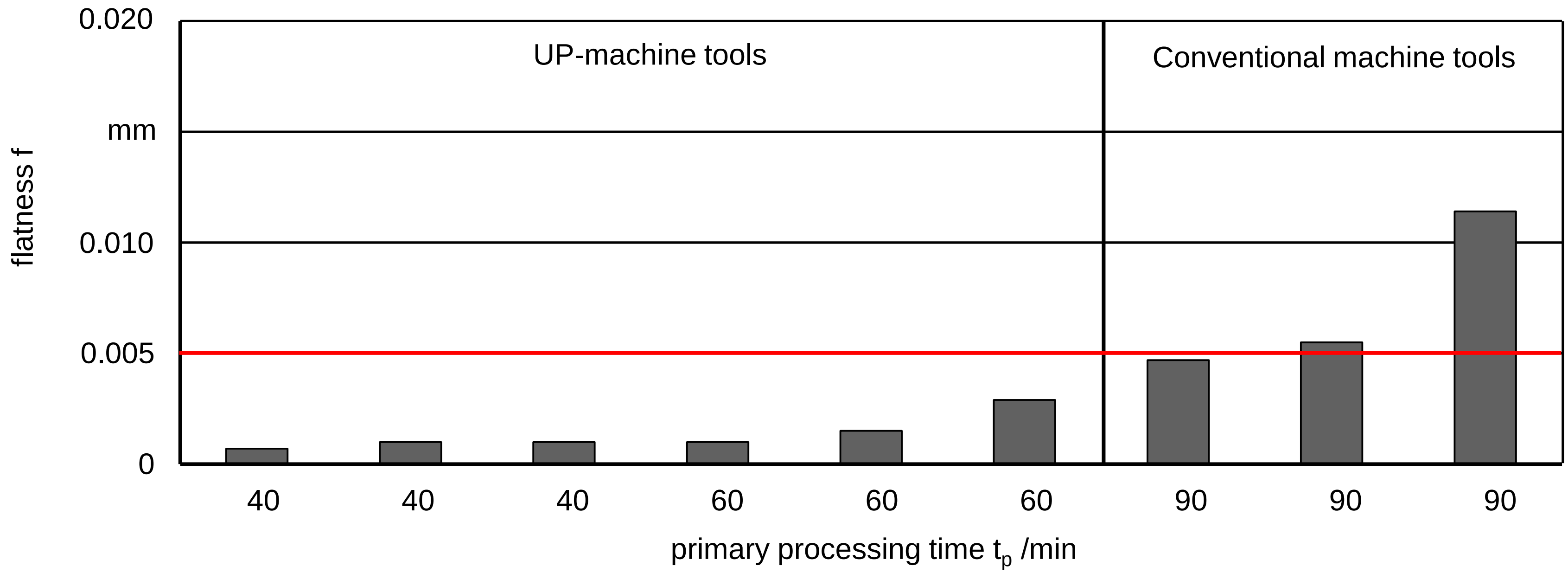


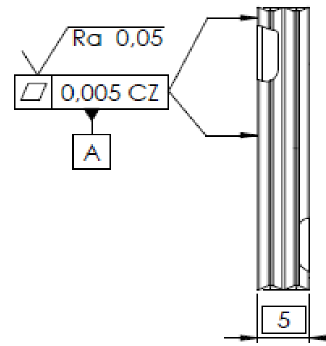


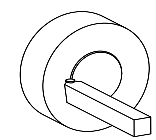


- Manufacturing result is independent from the process duration
- Machine tool class determines the result

Influence of Primary Processing Time
- turning of plane surface -



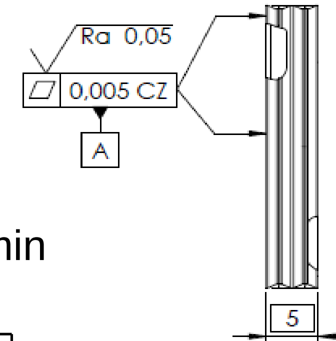


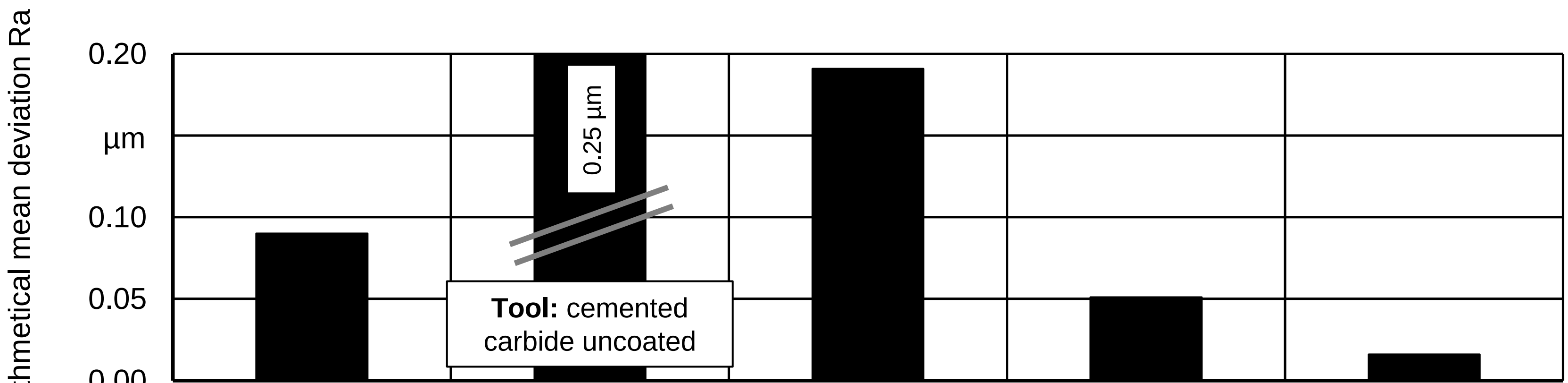


Influence of Technological Data on Arithmetical Mean Deviation Ra

Example high precision milling:

- Tool sharpness, and tool wear resistance influence the result
- Higher cutting speed vc leads to lower surface roughness
- TiAlN coated tungsten carbide tools are better than uncoated tools
- Width of cut ae is of lower importance with respect to the critical chip thickness hmin





f_z	0.02 mm
a_p	0.025 mm
a_e	0.9 mm
v_c	**101 m min^{-1}**

f_z	0.02 mm
a_p	0.2 mm
a_e	4.5 mm
v_c	**120 m min^{-1}**

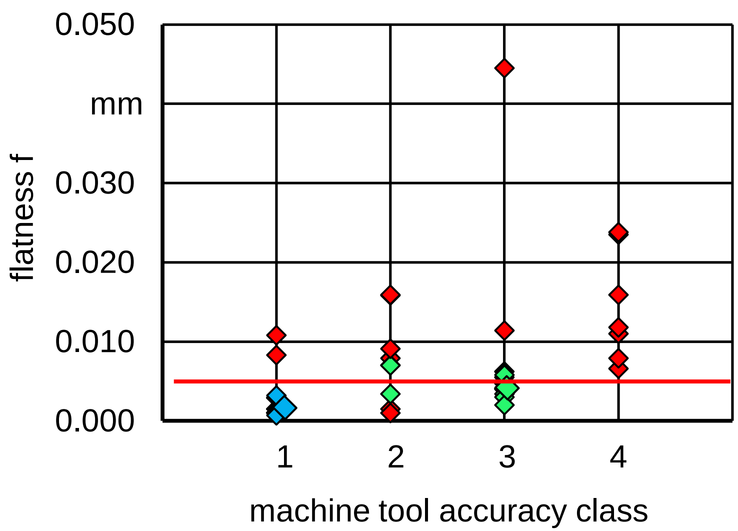
f_z	0.01 mm
a_p	0.1 mm
a_e	0.01 mm
v_c	**400 m min^{-1}**

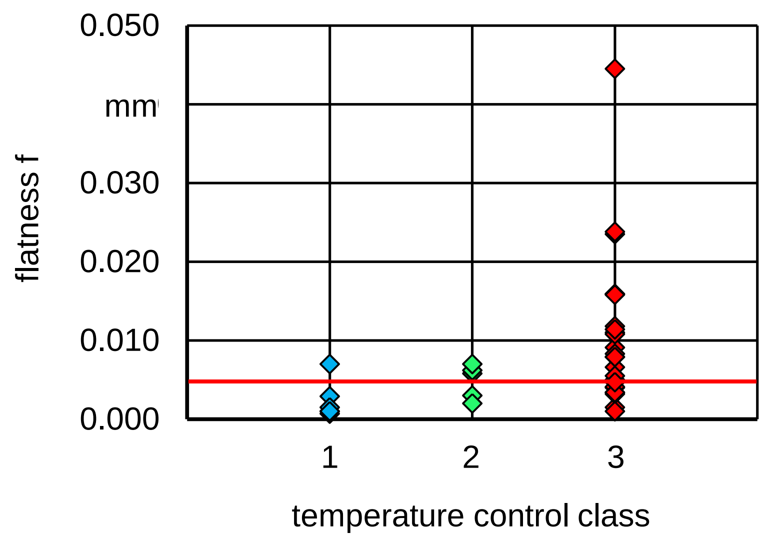
f_z	0.005 mm
a_p	0.1 mm
a_e	5 mm
v_c	**800 m min^{-1}**

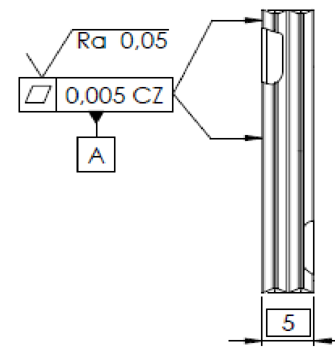
f_z	0.004 mm
a_p	0.02 mm
a_e	0.02 mm
V_c	**940 m min^{-1}**

Influence of Machine Tool Accuracy and Manufacturing Environment

- machining of plane surface -







Class 1:	ultra precision-class
Class 2:	high precision-class
Class 3:	precision-class
Class 4:	conventional class

Class 1:	ultra precision-class
Class 2:	high precision-class
Class 3:	conventional class

Capability of Series Production by Example of Pre-Machined Blanks

	arithmetical mean deviation Ra			
	flat surface		cylindrical surface	
	MV	U	MV	U
no.	µm	%	µm	%
1	0.013257	15	0.009205	15
2	0.011501	15	0.009572	15
3	0.010727	15	0.0089	15
4	0.01133	15	0.009579	15
5	0.01097	15	0.00945	15
6	0.012359	15	0.009175	15
7	0.012132	15	0.009815	15
8	0.012364	15	0.009608	15
9	0.011985	15	0.009887	15
10	0.01395	15	0.009517	15
11	0.015485	15	0.010043	15
12	0.01431	15	0.008679	15
13	0.015851	15	0.010085	15
14	0.015863	15	0.051345	15
15	0.012474	15	0.012574	15
16	0.014176	15	0.011066	15
17	0.014248	15	0.011034	15
18	0.013333	15	0.008522	15
19	0.013385	15	0.009083	15
20	0.014392	15	0.009528	15
21	0.014422	15	0.010371	15
22	0.014219	15	0.00821	15
23	0.014944	15	0.008791	15
24	0.013559	15	0.010365	15
25	0.008173	15	0.061593	15
26	0.014793	15	0.013695	15
27	0.013287	15	0.018274	15

Series production of high quality parts with more than one geometry feature is possible with

- one and the same machine tool of high accuracy
- one standardized technology
- specified tool type
- suitable environmental conditions

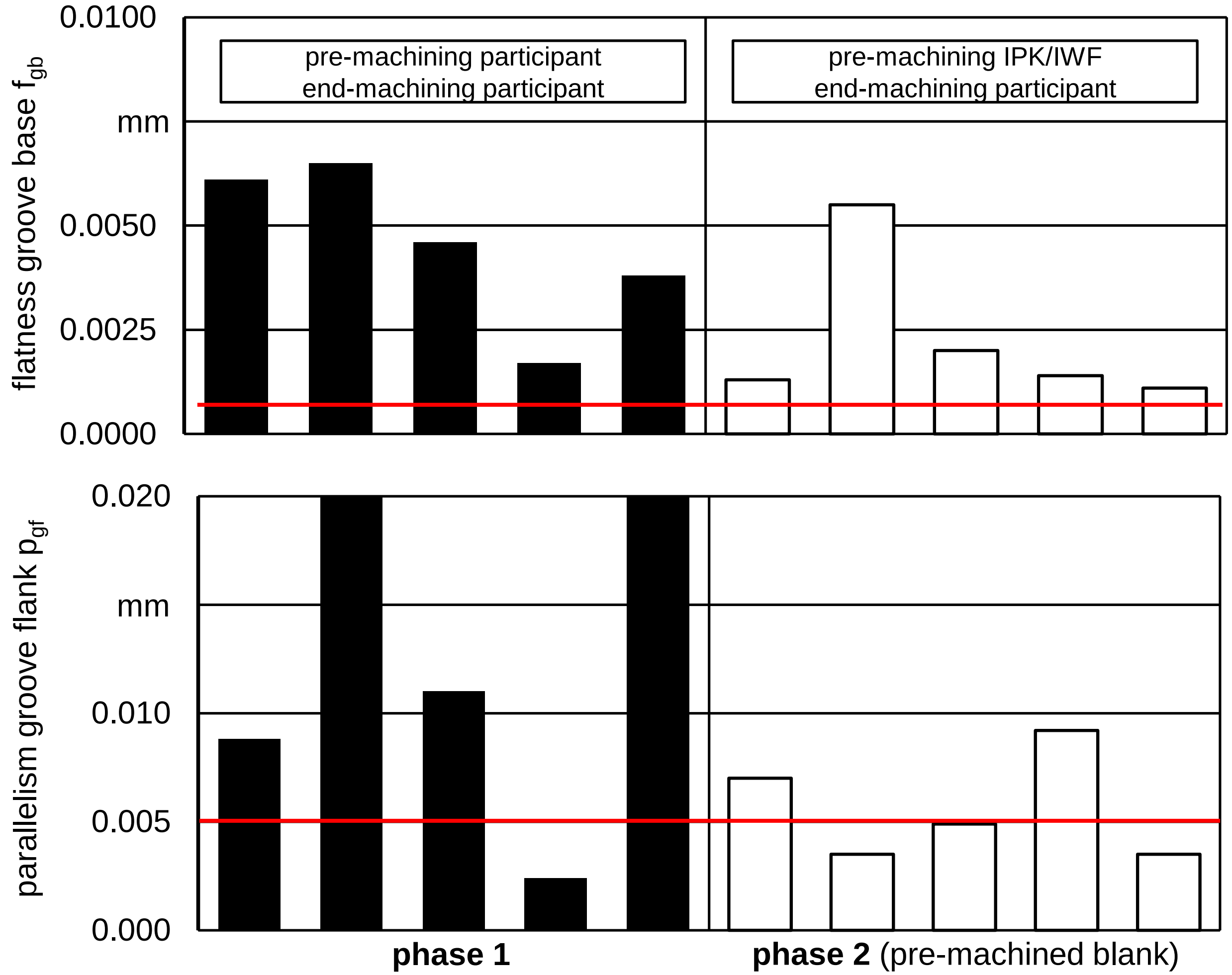
Blanks machined by IPK/IWF

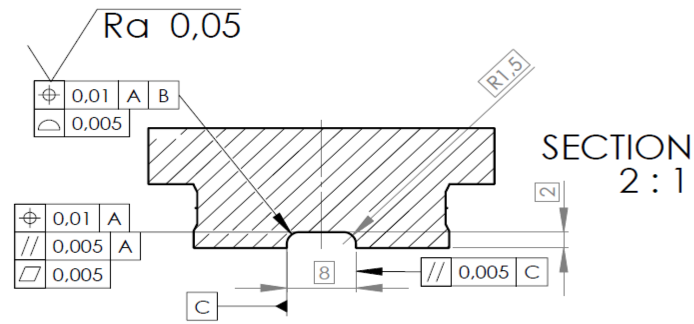
- constant machine tool conditions
- different lots
- different tools of the same specification

Capability of Series Production by Example of Pre-Machined Blanks

	flatness		cylindrical shape		circularity of midline		deviation of midline of diameter		perpendicularity	
	MV	U	MV	U	MV	U	MV	U	MV	U
no.	in mm	in µm	in mm	in µm	in mm	in µm	in mm	in µm	in mm	in µm
1	0.0007	0.6	0.0051	0.4	0.0027	0.5	29.4984	0.9	0.0005	0.3
2	0.0007	0.8	0.0041	0.4	0.0026	0.4	29.4985	0.9	0.0002	0.3
3	0.0003	0.8	0.0025	0.4	0.0023	0.4	29.4982	0.9	0.0002	0.3
4	0.0007	0.8	0.0022	0.8	0.0008	1.0	29.4984	1.0	0.0005	0.3
5	0.0007	0.7	0.0018	0.8	0.0009	0.9	29.4986	1.0	0.0003	0.3
6	0.0004	0.7	0.0030	0.5	0.0009	0.9	29.4982	0.9	0.0003	0.3
7	0.0005	0.7	0.0013	0.7	0.0010	0.8	29.4982	1.0	0.0004	0.3
8	0.0006	0.7	0.0017	0.7	0.0017	0.5	29.4981	1.0	0.0004	0.3
9	0.0004	0.7	0.0014	0.9	0.0009	0.9	29.4979	1.0	0.0005	0.3
10	0.0007	0.8	0.0030	0.7	0.0006	1.0	29.4977	0.9	0.0004	0.3
11	0.0005	0.7	0.0008	1.0	0.0006	1.0	29.4986	1.0	0.0002	0.3
12	0.0005	0.8	0.0058	1.0	0.0009	1.1	29.4976	0.9	0.0007	0.3
13	0.0005	0.7	0.0021	0.6	0.0008	1.0	29.4980	0.9	0.0006	0.3
14	0.0008	0.8	0.0009	1.0	0.0008	0.8	29.4977	1.0	0.0006	0.3
15	0.0008	0.8	0.0009	1.0	0.0006	1.0	29.4980	1.0	0.0009	0.3
16	0.0005	0.7	0.0165	0.8	0.0007	1.0	29.4983	1.0	0.0004	0.3
17	0.0006	0.8	0.0027	0.6	0.0008	0.9	29.4986	0.9	0.0018	0.3
18	0.0007	0.7	0.0011	0.9	0.0008	1.0	29.4984	0.9	0.0004	0.3
19	0.0005	0.8	0.0012	0.9	0.0008	1.0	29.4982	1.0	0.0002	0.3
20	0.0004	0.8	0.0011	0.9	0.0008	1.0	29.4978	1.0	0.0005	0.3
21	0.0008	0.7	0.0022	0.6	0.0007	1.0	29.4983	0.9	0.0010	0.3
22	0.0009	0.8	0.0013	0.9	0.0008	1.0	29.4984	0.9	0.0003	0.3
23	0.0006	0.7	0.0011	1.0	0.0009	1.0	29.4980	0.9	0.0004	0.3
24	0.0006	0.7	0.0013	0.8	0.0009	0.9	29.4985	1.0	0.0002	0.4
25	0.0024	0.5	0.0013	0.8	0.0012	0.8	29.4979	1.0	0.0013	0.3
26	0.0007	0.7	0.0012	0.9	0.0010	0.9	29.4980	0.9	0.0006	0.3
27	0.0004	0.8	0.0013	0.9	0.0011	0.9	29.4981	0.9	0.0003	0.3

Positive Effects while Machining of Grooves in Pre-Machined Blanks by HP-Milling





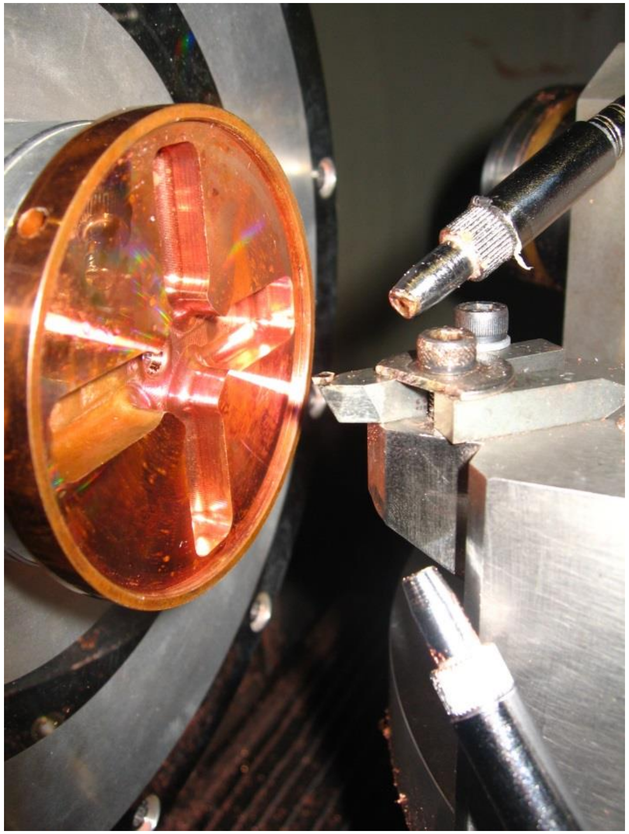
Phase 1:

- Participants worked with different conditions, based on their own experience

Phase 2:

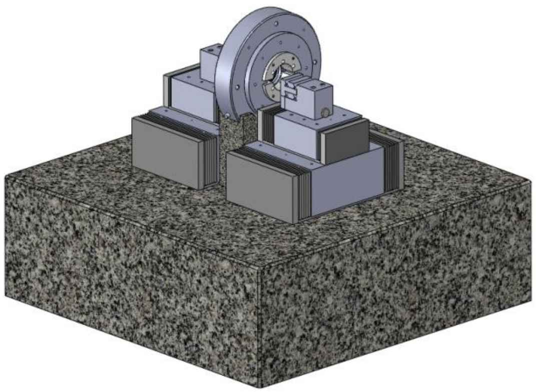
- Participants worked with comparable conditions:
  - technological parameters
  - milling tools

Summary and Conclusion



- Manufacturing protocols are possible, useful, and realistic.
- Cost effective standardized production of high volumes in specialized facilities provides reliable, reproducible quality.
- Challenges are logistics, handling, clamping.
- Investigations are necessary regarding error detection and suitable compensation.

Outlook – Proposal for BMBF-Funded Project



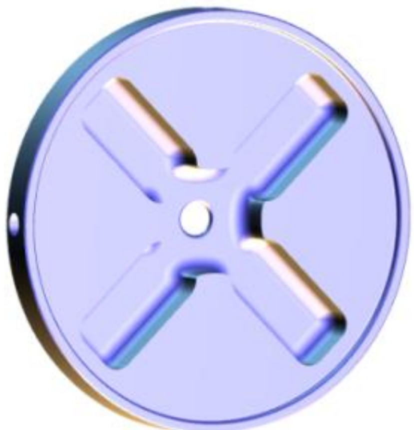
Machine tool concept

HP-Machining

Approach:

- Uncertainty analysis
- Modelling and simulation of ultra-precision machining
- Analysis of the workpiece material during the machining process
- Statistically verified analysis of manufacturing technologies
- Analysis of measurement methods and determination of the measurement strategies
- Development of a machine tool for two side ultra-precision-machining
- Design of production process chains for machining of CLIC structures – capability was shown in the CIRP CWG

Outlook – Proposal for BMBF-Funded Project

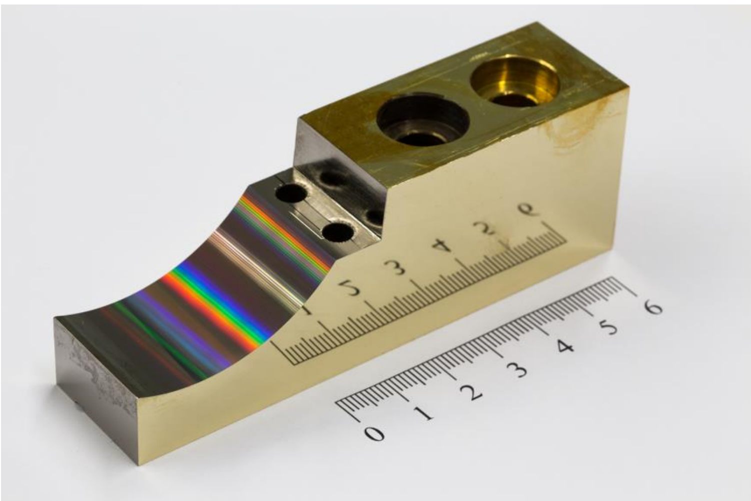


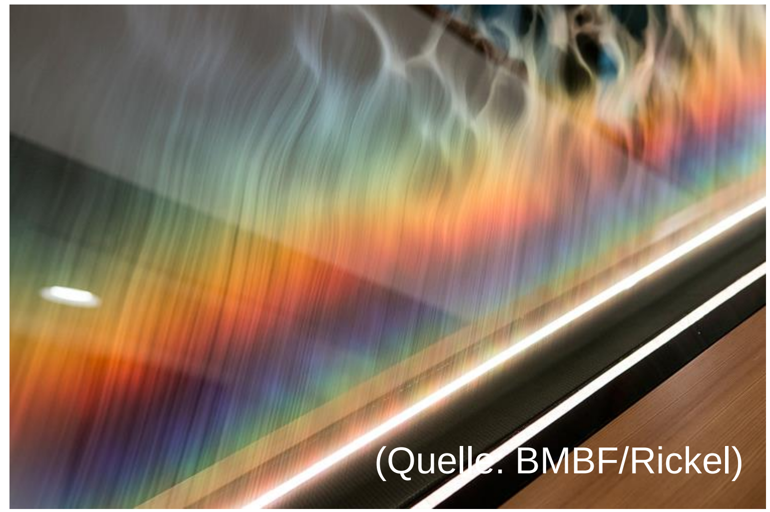
CLIC-part CLIAAS110337

Goals:

- Optimized process chains for manufacturing CLIC-parts and X-band structures (latest design will be provided by CERN)
- Knowledge about manufacturing deviation
- Standardized measurement processes
- Investigations regarding new evaluation methods for CLIC-part machining results
- Cost effective machining:
    - Less influence of personnel due to standardized, automated processes
    - Decreased process duration
    - Reduced number of parts out of tolerance

Process Example IPK: Injection Molding Tool and Injection Embossing Process for an Art Project at the new BMBF Building





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