Traceable In-Process Dimensional Measurement

Operation and behaviour of a climate simulation chamber developed for investigations of thermal effects on machine tools

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Physikalisch Technische Bundesanstalt, Braunschweig, May 18th, 2016

wbk Institute of Production Science

Agenda

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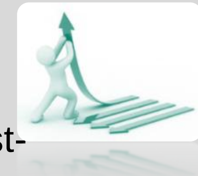
Traceable in-process dimensional measurement
Work Package Motivation

Idea

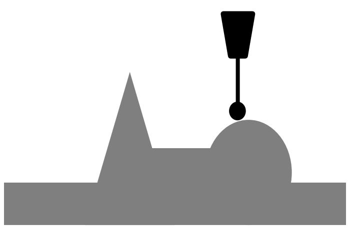


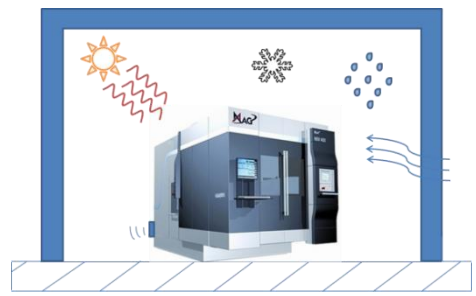
Development of in-process measurement
in machine tools as an enabler for cost-efficient quality assurance systems

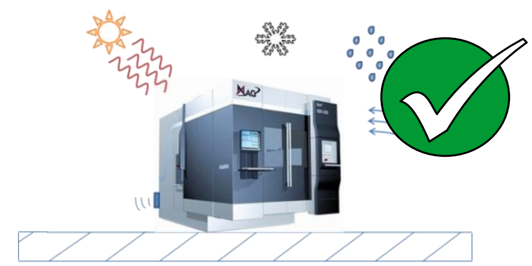
Potential

Reduction of production costs

- Increase of quality
- Highly precise measurement on the shop floor
- No additional coordinate measurement systems







Calibration standard

Development of a calibration procedure, which is not affected by environmental conditions and is measured in the machine tool

Climatic simulation chamber

Mobile simulation chamber to imitate harsh shop floor conditions and their influence on in-process measurement systems of machine tools

Real shop floor

Increase of the production quality by compensation of the effects of environmental conditions on the measurement system

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Traceable in-process dimensional measurement
Preliminary investigations

Process

- Serial production of varying automotive components by milling
- Initial situation:
  - Manual gauges used up to 5 times per shift
  - Additional CMM used at least once per shift and after each tool change

Analysis

- Potential for reduced costs due to reduced transportation and process times
- Acquisition of duration times for transportation, tool change, machining and measurement times
- Different scenarios include varying change of tools, CMM measurements and number of calibrations

I	II	III	IV
1 Tool change	1 Tool change	2 Tool changes	1 Tool change
1 x CMM	2 x CMM	2 x CMM	1 x CMM
			1 x Calibration

Results

- General conclusion:
  High amount of variants of one manufactured part that requires an increased number of tool changes and measurements leads to monetary benefits
- Reduced costs per piece by 5-10% depending on considered scenario

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Traceable in-process dimensional measurement
Technical boundaries

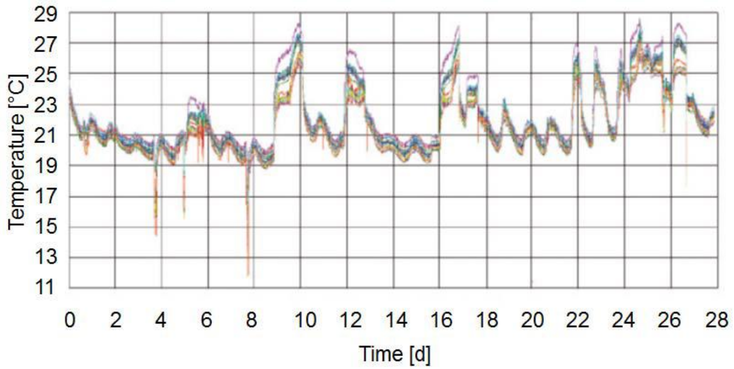
Operation conditions

- Outside temperatures: 18°C – 35°C
- MT-Dimensions: 5.2 x 3.6 x 3.7 m³
- Heat emission: 24 kW
- Temperature homogeneity: ±2 K
- Cooling/heating rate: ±3 K/h

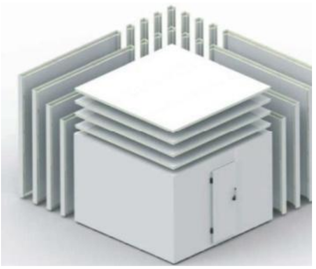
Concept

- Combination of isolating and load-bearing wall elements
- Modular structure for adaptable dimensions
- Maximum dimensions: 6 x 10 x 5 m³
- Temperature regulation: **15°C – 45°C**
- Interfaces for sensors
- Maximum of 40 m distance between conditioning components and climate chamber

Dimensioning of conditioning units?



Typical temperature change on the shop floor [wzl]



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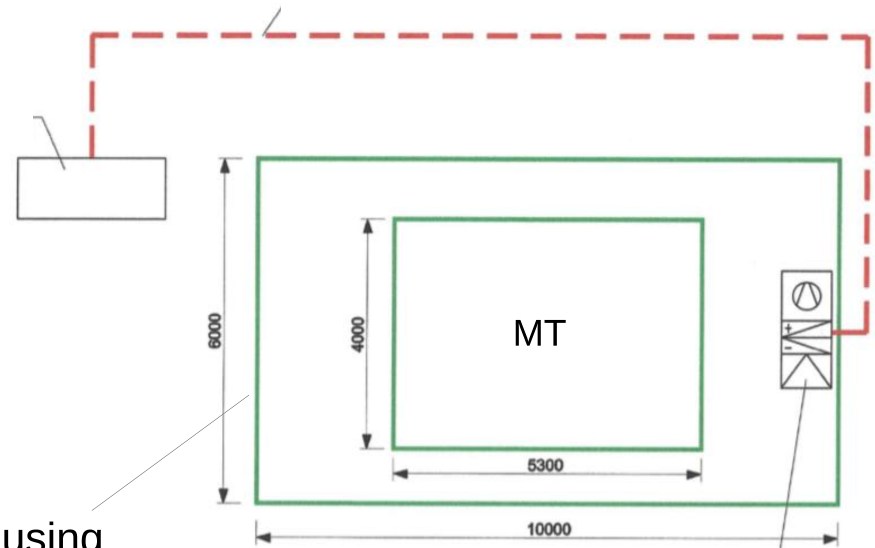
Traceable in-process dimensional measurement
System structure

- Cold water pipes
  - Conduction of carrier medium
- Coldwater-/Recooler-/Pump-/Expansion-Module



- Housing
- RLT-device
  - Suction/Fan

Climatic components

- According to the most energy-intensive operating condition the resulting cooling load amounts **26 kW** including emitted heat by the MT and draft effects
- Resulting rate of conditioned air: **8.000 m³/h**
- Required rate of fresh air: **300 m³/h**

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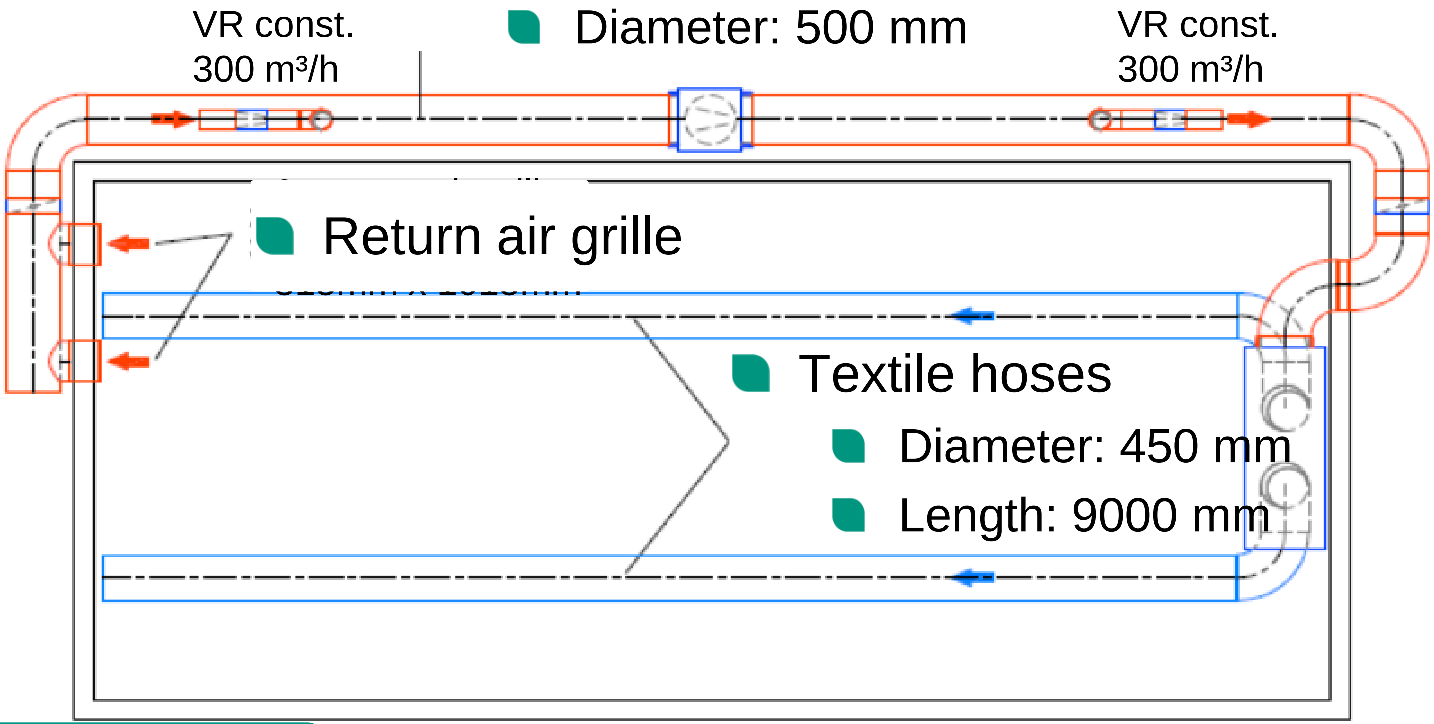
Traceable in-process dimensional measurement
System structure

- Return air pipe
  - Diameter: 500 mm
- Return air grille
- Textile hoses
  - Diameter: 450 mm
  - Length: 9000 mm



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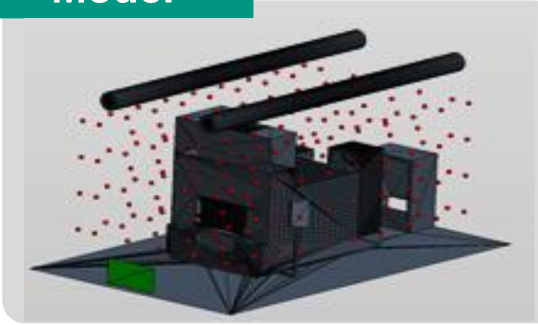
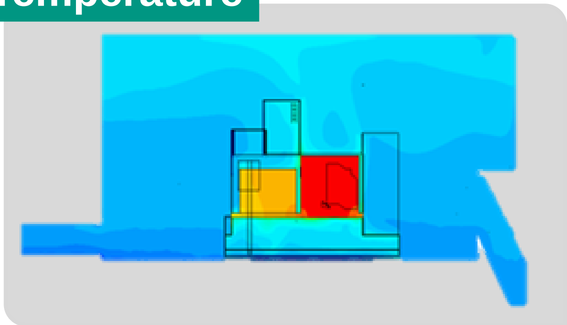
Traceable in-process dimensional measurement
Digital model

- Assumptions
  - Inlet temperatures: 5°C – 45°C
  - Mean specific heat capacity: 37 J/kgK
  - Air density: 1.184 kg/m³
- Software
  - StarCMM
  - Solver:
    Boussinesq, K-Epsilon Turbulence,
    Realizable K-Epsilon Two-Layer,
    Reynolds-Averaged Navier-Stokes,
    Two-Layer All y+ Wall Treatment
- Goal:
  - Verification of preliminary calculations
  - Identification of critical temperature and flow velocity zones in stationary conditions that might disturb sensors or other equipment

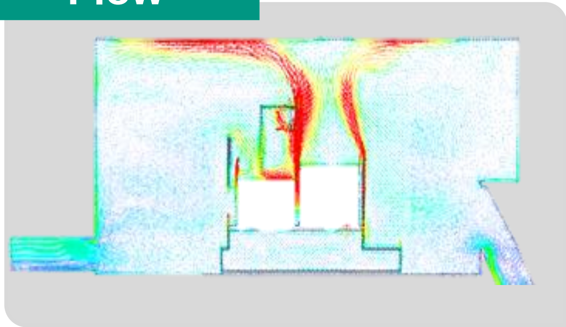
Model



Temperature



Flow



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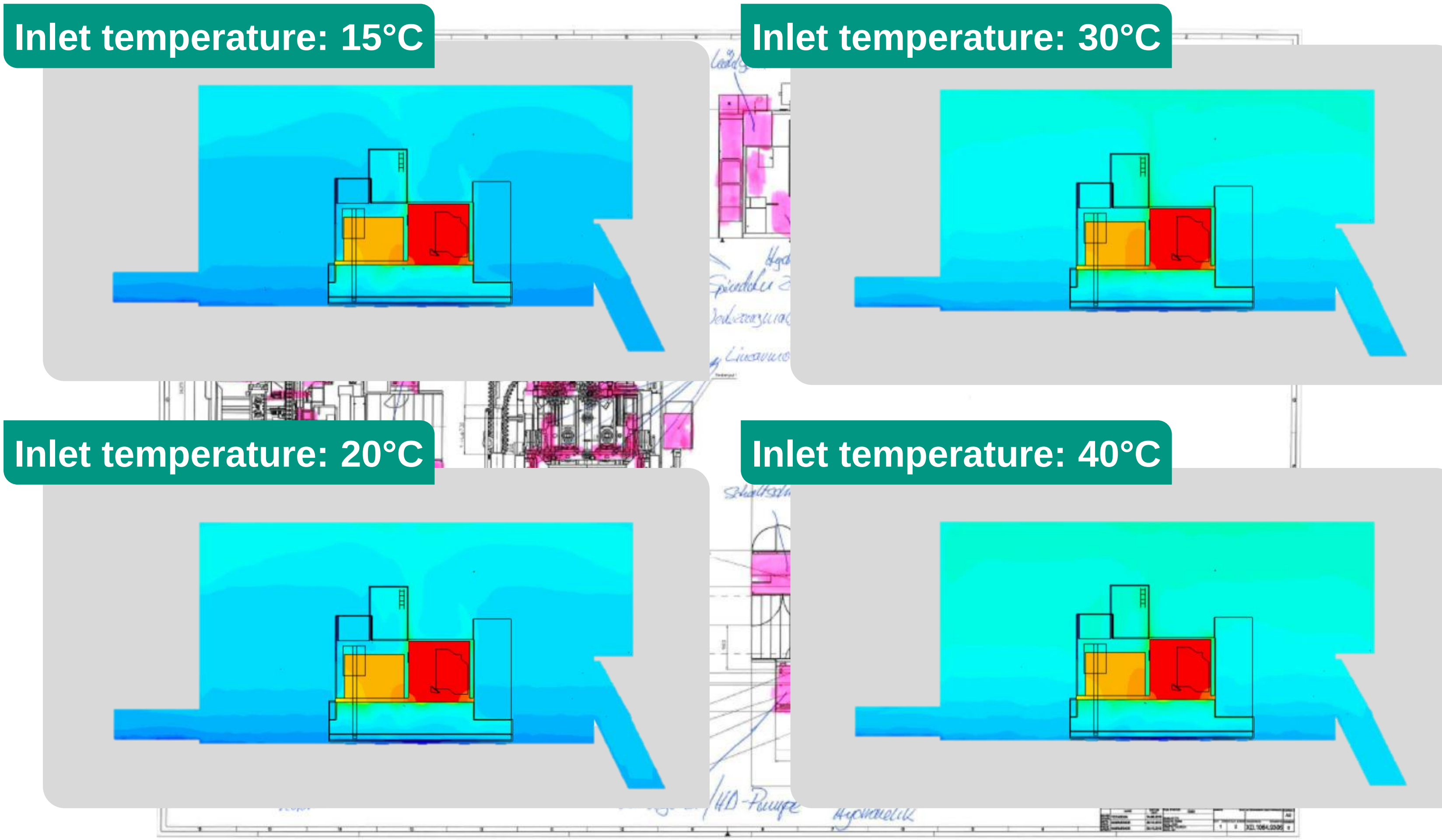
Traceable in-process dimensional measurement
Modeling and simulation



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Traceable in-process dimensional measurement
Temperature

Inlet temperature [°C]	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C	45°C
Mean temperature [°C]	35.4	37.8	39.5	40.7	42.8	46.6	47.0	49.3	50.4
Maximum temperature [°C]	42.3	44.5	46.0	50.8	46.5	51.4	52.3	53.9	54.8
Minimum temperature [°C]	33.7	36.1	37.2	37.7	39.0	41.9	42.1	43.7	45.2
Std. deviation (n=192) [°C]	**1.16**	**1.24**	**1.36**	**1.62**	**1.80**	**2.14**	**2.33**	**2.51**	**2.68**

Interim conclusion

- Inhomogeneity within acceptable range

Traceable in-process dimensional measurement
Flow velocities

Inlet temperature [°C]	5°C	10°C	15°C	20°C	25°C	30°C	35°C	40°C	45°C
Mean velocity [m/s]	0.09	0.09	0.07	0.08	0.09	0.08	0.08	0.08	0.08
Maximum velocity [m/s]	**0.59**	**0.55**	**0.3**	**0.36**	**0.48**	**0.52**	**0.55**	**0.46**	**0.44**
Minimum velocity [m/s]	≈0	≈0	≈0	≈0	≈0	0.01	0.01	≈0	0.01
Std. deviation (n=192) [m/s]	0.06	0.06	0.04	0.05	0.06	0.06	0.05	0.05	0.05

Interim conclusion

- No significant effects of flow velocities on people or used equipment inside the climate chamber

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Traceable in-process dimensional measurement
Climate Simulation Chamber

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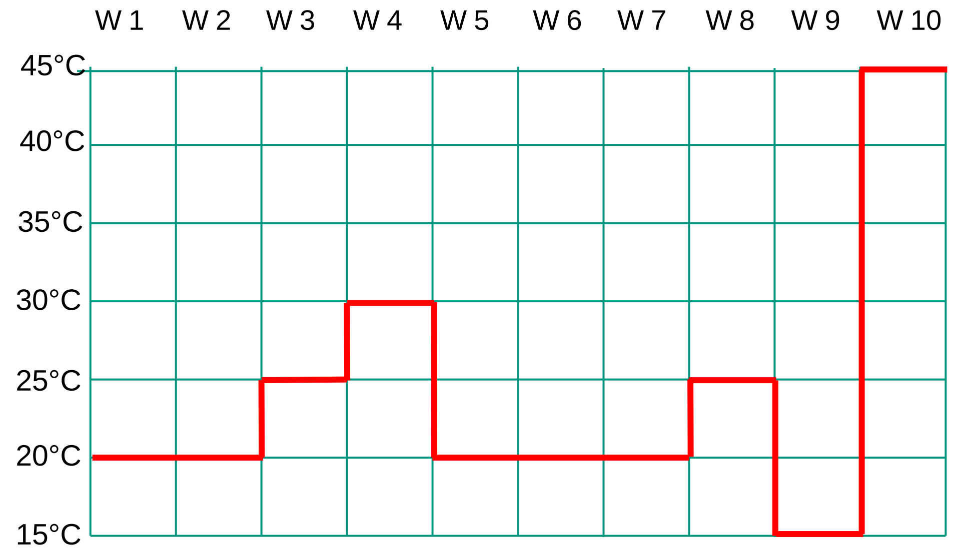
Traceable in-process dimensional measurement
Validation

Test profile requirements

- Heat up of MT:
  2 days
- Hold time for error detection:
  5 days



Sensor network

- 7 Sensor knots
- Each knot consists of 3 single sensors evenly distributed over the height

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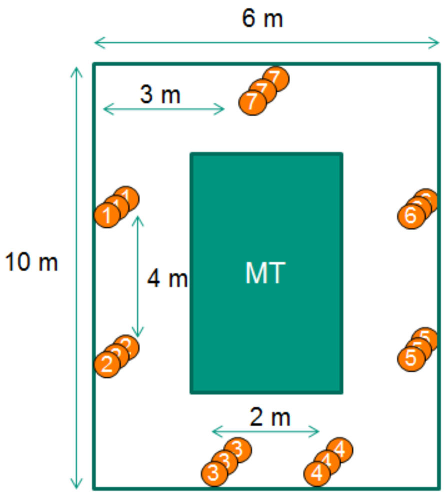

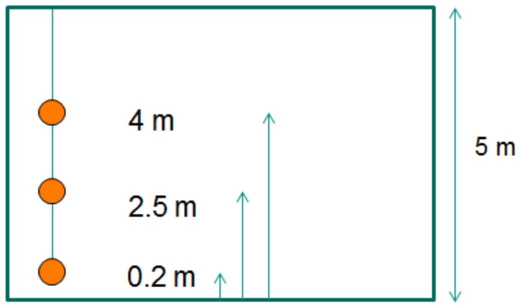

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Sensors

- Wall near sensors

- Machine near sensors (I)

- Machine near sensors (II)

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Traceable in-process dimensional measurement
Statistical evaluation

Target Temperature [°C]	Knot	Mean temperature [°C]			Std. deviation [°C]			Max. spread [Δ°C]		
	x	x.1	x.2	x.3	x.1	x.2	x.3	x.1	x.2	x.3
15	1	15.55	15.68	15.55	0.2	0.21	0.14	1.07	1.12	0.74
	2	15.68	15.48	15.7	0.21	0.23	0.14	1.12	1.36	0.76
	3	15.55	15.7	15.46	0.14	0.14	0.1	0.74	0.76	0.67
	4	15.48	15.03	15.34	0.23	0.21	0.15	1.36	1.22	0.88
	5	16.37	15.37	15.26	0.09	0.1	0.07	0.6	0.57	0.41
	6	15.7	15.34	15.12	0.14	0.15	0.12	0.76	0.88	0.81
	7	15.15	15.68	15.46	0.14	0.12	0.18	0.79	0.67	0.96
Mean values		**15.50**			**0.15**			**0.87**		

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Traceable in-process dimensional measurement
Statistical evaluation

Target Temperature [°C]	Knot	Mean temperature [°C]			Std. deviation [°C]			Max. spread [Δ°C]		
	x	x.1	x.2	x.3	x.1	x.2	x.3	x.1	x.2	x.3
20	1	20.46	20.21	20.31	0.61	0.56	0.27	2.19	2.12	1
	2	20.21	20.52	20.47	0.56	0.24	0.44	2.12	1.09	1.67
	3	20.31	20.47	20.26	0.27	0.44	0.19	1	1.67	0.79
	4	20.52	19.97	20.41	0.24	0.5	0.23	1.09	1.74	1.05
	5	20.55	20.2	20.25	0.36	0.18	0.14	1.48	0.81	0.6
	6	20.47	20.41	20.09	0.44	0.23	0.26	1.67	1.05	0.95
	7	20.31	20.39	20.21	0.35	0.14	0.49	1.21	0.71	1.76
Mean values		**20.33**			**0.34**			**1.32**		

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Traceable in-process dimensional measurement
Statistical evaluation

Target Temperature [°C]	Knot	Mean temperature [°C]			Std. deviation [°C]			Max. spread [Δ°C]		
	x	x.1	x.2	x.3	x.1	x.2	x.3	x.1	x.2	x.3
25	1	25.72	25.28	25.42	0.41	0.35	0.17	2.58	1.77	0.99
	2	25.28	25.36	25.6	0.35	0.19	0.3	1.77	0.97	1.85
	3	25.42	25.6	25.07	0.17	0.3	0.16	0.99	1.85	0.75
	4	25.36	24.81	25.24	0.19	0.43	0.24	0.97	2.37	2.32
	5	25.36	24.73	25.07	0.25	0.21	0.14	1.53	3.01	0.75
	6	25.6	25.24	25.12	0.3	0.24	0.28	1.85	2.32	4.72
	7	25.35	24.6	25.44	0.29	0.15	0.35	1.65	1.83	4.47
Mean values			**25.27**			**0.26**			**1.97**	

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Traceable in-process dimensional measurement
Statistical evaluation

Target Temperature [°C]	Knot	Mean temperature [°C]			Std. deviation [°C]			Max. spread [Δ°C]		
	x	x.1	x.2	x.3	x.1	x.2	x.3	x.1	x.2	x.3
30	1	30.74	30.13	30.27	0.16	0.13	0.12	1.42	1.16	0.61
	2	30.13	30.02	30.51	0.13	0.24	0.15	1.16	0.98	0.96
	3	30.27	30.51	29.72	0.12	0.15	0.13	0.61	0.96	0.6
	4	30.02	29.62	29.94	0.24	0.18	0.19	0.98	1.5	0.88
	5	29.96	29.2	29.73	0.14	0.12	0.1	0.91	0.65	0.53
	6	30.51	29.94	29.95	0.15	0.19	0.11	0.96	0.88	0.78
	7	30.17	28.98	30.37	0.16	0.1	0.16	1.03	0.52	1.08
Mean values			**30.03**			**0.15**			**0.91**	

Conclusion

- Fluctuations within the targeted tolerance range of ±2 K
- Perfomance: **+15 K/h** & **-13.34 K/h**

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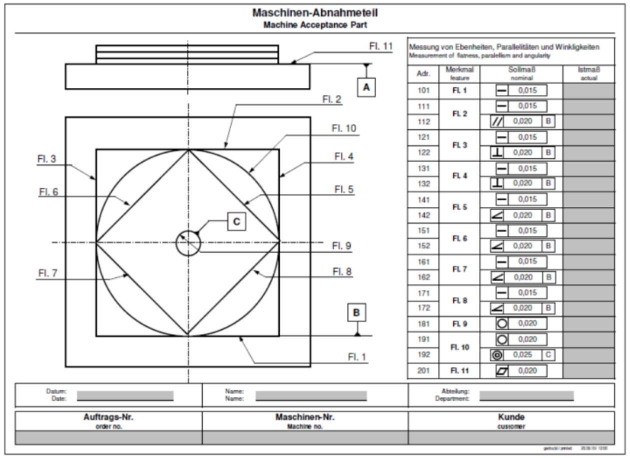
Traceable in-process dimensional measurement
Task specific measurement uncertainties



Messung von Ebenheiten, Parallelitäten und Winkligkeiten
Measurement of flatness, parallelism and angularity

Adr.	Merkmal feature	Sollmaß nominal	Istmaß actual
101	Fl. 1	— 0,015	
111	Fl. 2	— 0,015	
112		// 0,020 B	
121	Fl. 3	— 0,015	
122		⊥ 0,020 B	
131	Fl. 4	— 0,015	
132		⊥ 0,020 B	
141	Fl. 5	— 0,015	
142		∠ 0,020 B	
151	Fl. 6	— 0,015	
152		∠ 0,020 B	
161	Fl. 7	— 0,015	
162		∠ 0,020 B	
171	Fl. 8	— 0,015	
172		∠ 0,020 B	
181	Fl. 9	○ 0,020	
191	Fl. 10	○ 0,020	
192		◎ 0,025 C	
201	Fl. 11	▱ 0,020	

Definition of an industrial approval part geometry

Measurement

Calibration

Manufacturing with and without active error compensation

↓

Measurement of the manufactured charactertics on the machine tool

↓

Calibration of the characteristics under laboratory conditions

↓

Determination of the measruement uncertainty

↓

Evaluation of the applicability of the MT as measuring equipment

Thank you for your attention!

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