Thermal Effects on Measurement Processes on Machine Tools

Measurement uncertainty evaluation in a controlled climate surrounding

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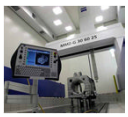
Zurich

Motivation

Typical Post-Process-Inspection in the production chain of a large scale device!


Manufacturing Process


Inspection Process

- Interuption of the manufacturing process
- Loss of original Clamping
- Transport
- Temperature Gradients

Motivation

On-Machine-Measurement (OMM)

- On-Machine-Measurement: Integration of the measurement process into the machine tool!
- Substitution of CMM only for traceable measurement processes!

Determination of the measurement uncertianty for the complete measuring system!
Influence of thermal loads as show stopper?

Agenda

1. **On-Machine Measurements**
2. **Uncertainty evaluation for the measurement system**
3. **Thermal effects on the measurement process**
4. **Guidelines for traceable measurements on machine tools**

Influences on Manufacturing Process

Influence	Manufacturing Process	Measurement Process
Force (Milling, Drilling,…)	●	○
Machine Tool Errors (geometric)	●	●
Temperature (Process)	●	◔
Temperature (Surrounding)	●	●
Workpiece Surface	◑	◑
Tool Wear	●	○
Gravitation Workpiece	●	●
Manufacturing Programm	●	○
Operator Error	●	○

Critical parameters are influencing both manufacturing and measurement process!

Ensuring Traceability
Test Set Up:Traceability of Measurements using Machine Tools

Transfer of CMM methods for MT

- DIN EN ISO 15530-4
  - Cooperation with PTB
  - Adaption of the vCMM for machine tool kinematic and challenges
- DIN EN ISO 15530-3
  - Design and calibration of standard for a range of special tasks
  - Selected tasks measured and evaluated (Software) as described in DIN
- VDI 2617-11
  - Current research
  - MPE for machine tools

Kinematic
- 5-Axis Machine Tool Hermle B300U
- Calibrated with Laser Tracer

Touch-probe
- M&H IR HDR
- BLUM TC 76
- Heidenhain TS440
- Renishaw RMP 600

Software
- Task Specific Analysis (own Approach)
- Integration of Commercial Products

Un-certainty

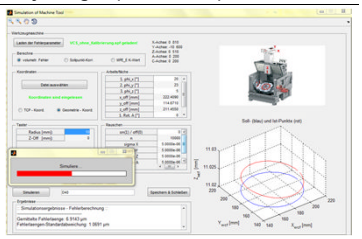
Work-piece
- Specially designed standard for various tasks

[1] Mayr, J. et al., Thermal issues in Machine Tools, CIRP Annals, 2012
[2] Henzold, G.: Anwendung der Normen über Form- und Lagetoleranzen in der Praxis, DIN-Normenheft 7, Beuth Verlag

Machine Integrated Traceable Metrology
Determination of the Uncertainty Budget (VDI 2617-11)

Softwarebased Approach for a measurement uncertainty budget according to VDI 2617-11

- Input:
  - Machine Parameters
  - Measurement Task
  - Workpiece Parameters
  - Environmental Conditions
  - …
- Result:
  - Taskspecific Measurement Uncertainty
  - Linked to temperature range during calibration
  - User-friendly software for a quick uncertainty determination



Thermal effects in machine tool structure
Temperature memory of the machine tool structure

Test setup:

- Controlled environment in climate chamber
- Machine tool is equipped with temperature sensors on the structure
- Machine tool surrounding is additionally surveilled by external temperature sensors
- Temperature in the chamber is changed as shown in the blue line (static for 8h)
- Structure reaction visualized with colored lines in diagram

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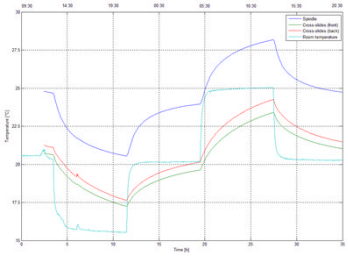
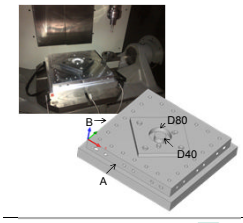
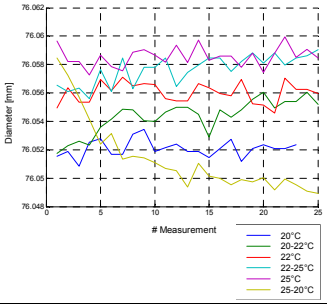


Delay between surrounding temperature and structure temperature:
➢ Temperature gradients inside the structure!

Thermal effects in machine tool structure
Thermal effects on the measurement process

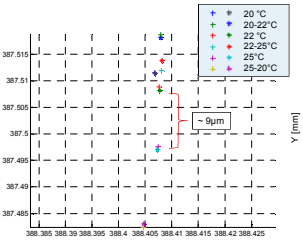
- Measured Task: Diameter D80
- Touch Probe Diameter: Uncompensated
- Visualization of thermal influence on workpiece and structure?



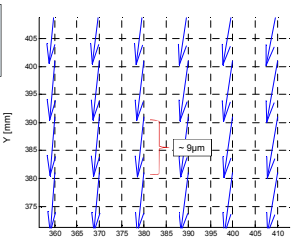


Thermal effects in machine tool structure
Thermal effects on the measurement process

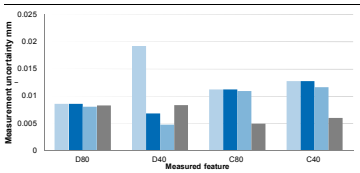
Center of the measured circles

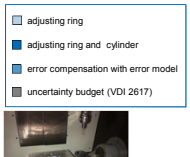


Volumetric errors of the machine tool



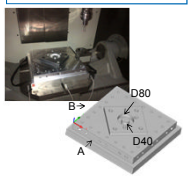
Thermal effects in machine tool structure
Determination of the measurement uncertainty





$$U = k \times \sqrt{u_{cal}^2 + u_p^2 + u_w^2 + b^2}$$

- u_{cal}: standard uncertainty calculated from the uncertainty of calibration of the calibrated workpiece
- u_p: standard uncertainty of the measurement process
- u_w: standard uncertainty influenced by the material of the work piece*
- b: systematic deviation between y_i and the calibrated value x_{cal}
- k: coverage factor

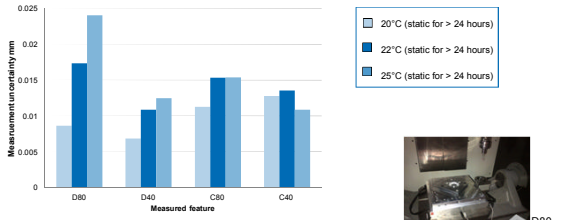


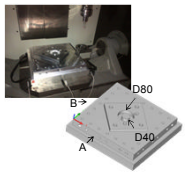
* for length measurements (inkl. position, diameter):

$$u(L) = L + \sqrt{\left[\Delta T_W\right]^2 + u(\alpha_W)^2 + \alpha_W^2 + u(\Delta T_W)^2}$$

[3] Hemia, M.: Uncertainty of coordinate measurements, QZ, 2010
[4] DIN ISO 15530 Geometrical product specifications (GPS):Coordinate Measuring Machines (CMM), Beuth
[5] DIN: *Guide to the Expression of Uncertainty in Measurement*, Beuth Verlag GmbH, 1995

Thermal effects in machine tool structure
Determination of the measurement uncertainty





- Extension to temperature gradients
- Extension to internal thermal load
- Need for an active compensation of the induced errors

Machine Integrated Traceable Metrology
Guidelines for traceable measurement using machine tools

- Configuration of measurement system
- Minimization of disturbing factors
- Traceability of measurement results
- Monitoring of measurement system
- Examination of product characteristics

Configuration and Calibration

- Detection of geometry errors of the machine tool (global detection of position deviation)*
- Detection of position deviation for specific measurement task (measurement points)*
- Detection of geometric contact deviation of the touch probe

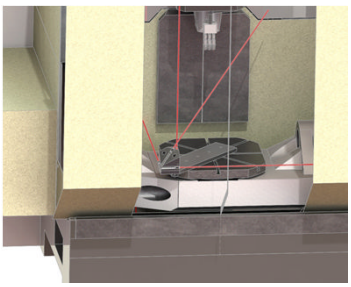
* at a specific temperature point

Monitoring of the measurement system

- Need for Interims-Test for measurement system's capability
- Different Approaches known from machine tool testing seem to be capable (DIN ISO 230)
- Test has to be quick and user-friendly
- Standards or laser based methods in large volumes

[6] Sartori, Zhang, *Geometric error measurement ad compensation of machines*, CIRP Annals, 1995
[7] Schwenke, Knapp, Haitjema, Weckenmann, Schmitt ,Delbressine, *Geometric error measurement ad compensation of machines- An update*, CIRP Annals, 2008 [6], [7]

Absolute MultiLine
Traceability in Large Volume Metrology



Measurement uncertainty
- DIN EN ISO 15530-4
  - Cooperation with PTB
- VDI 2617-11
  - MPE for machine tools

Thermal Issues:
- Internal thermal load
- Calibration during heating period
- „In-situ" compensation

Quick Check of Machine Tools Performance
- Traceability for the measurement process as a permanent reference system
- Material or optical reference

Appendix

[1] Mayr, J. et al., Thermal Issues in Machine Tools, CIRP Annals, 2012
[2] Henzold, G.: Anwendung der Normen über Form- und Lagetoleranzen in der Praxis, DIN-Normenheft 7, Beuth Verlag
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