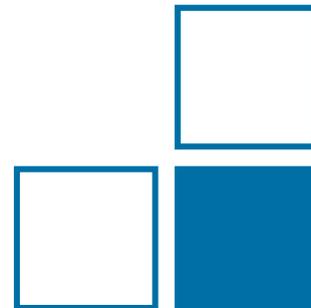


Determination of measurement uncertainty for large involute gears by means of Monte Carlo method

3D Metrology Conference, London, GB
6th November 2019

Ann-Kathrin Wiemann, M.Sc.
Dr. Martin Stein, Dr. Karin Kniel



National Metrology Institute of Germany



221 Mio. €
budget*



2000
Employees,
including
200 PhD
Students**



60%
Research
work



560
publications*



186 patents**
> 80
concessions*



Responsibilities
of public
administration
due to > 20 laws
and regulations*



> 120 intern.
and national
committees*



* in 2017
** in 2018

Department 5.3: Coordinate Metrology



Department 5.3: Coordinate Metrology
Dr.-Ing. Karin Kniel

~ 42 Employees

→ 24 Permanent Employees



WG 5.31: Geometrical Standards

Dr. rer. nat. Otto Jusko



WG 5.32: Coordinate Measuring Systems

Dr. rer. nat. Daniel Heißelmann



WG 5.33: Gears and Threads

Dr. rer. nat. Martin Stein



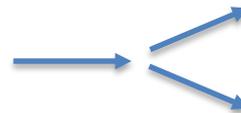
WG 5.34: Multisensor Coordinate Metrology

Dr.-Ing. Ulrich Neuschaefer-Rube



WG 5.35: 3D-Calibrations

Dipl.-Ing. (FH) Jürgen Hirsch



D = 20 mm

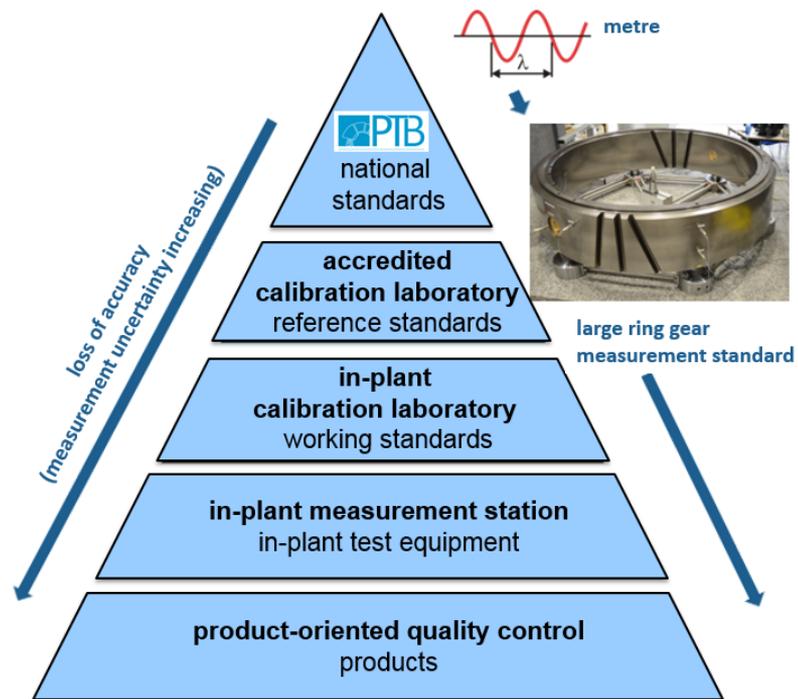


D = 2000 mm



Motivation

- Reliable quality assurance of products like large drivetrain components
 - Identify defect production
 - Reduce failure rates of drivetrains from wind energy systems
- Traceable measurements
 - Value for measurand
 - Measurement uncertainty
 - Complex task
 - Easy-to-use tool



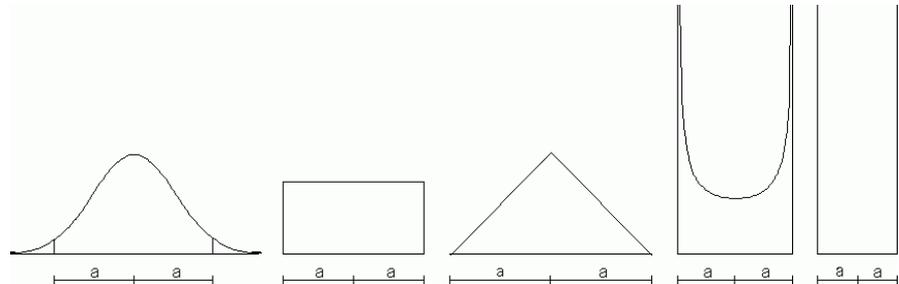
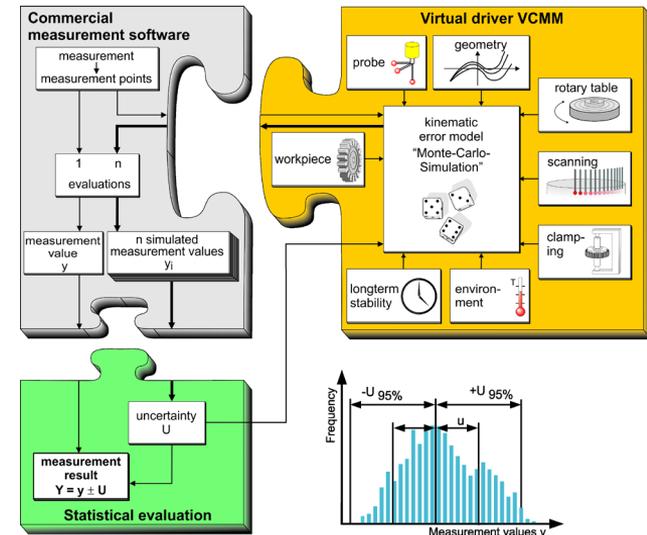


Virtual Coordinate Measuring Machine (VCMM)

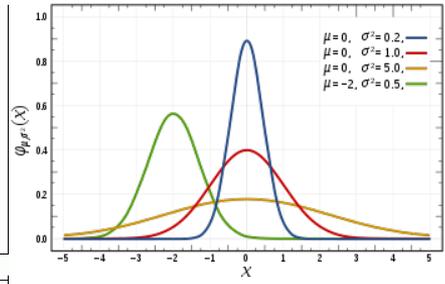


VCMM

- Virtual CMM generate a task-specific uncertainty estimation
- For small measurement volume of portal CMM the VCMM is established
- For large measurement tasks the VCMM need adjustments
- Characterization of behaviour of influences
- Model \rightarrow distribution type and parametrization



source: VDI/VDE 2617 Sheet 11 (2009)



source: Wikipedia.de

General process

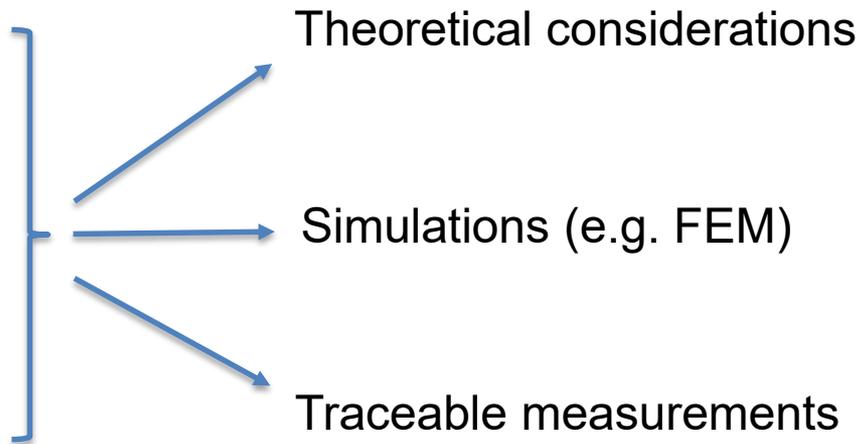
Measurement process



What are the main influences?



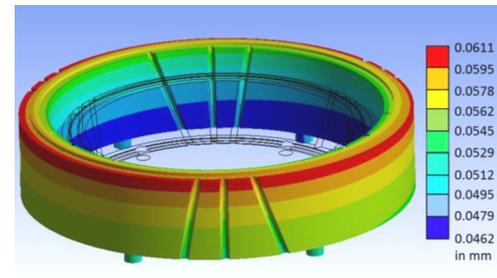
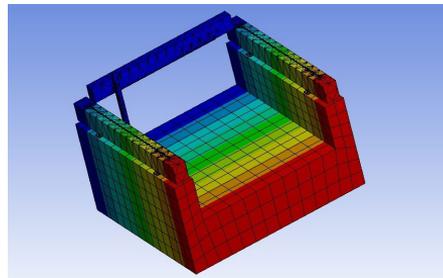
How does they affect the measurement value?



Mathematical models of distribution for Monte Carlo sampling



$$X \pm U$$

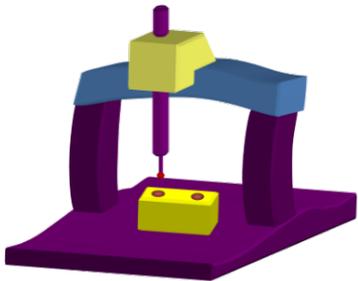


Components of measurement process

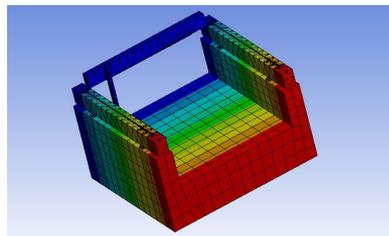
- Large coordinate measuring machine
 - Leitz PMM-G
 - 5 m x 4 m x 2 m
- Large measurement standard
 - Involute gear ring ($\varnothing = 2$ m)
 - Internal and external gear groups
 - With 6 point clamping



Relevant influences



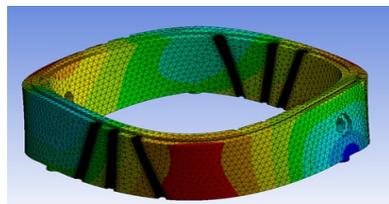
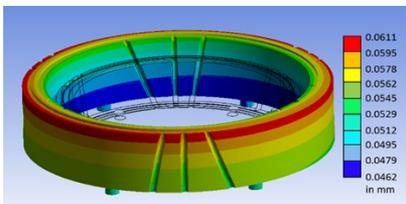
Geometric error of CMM



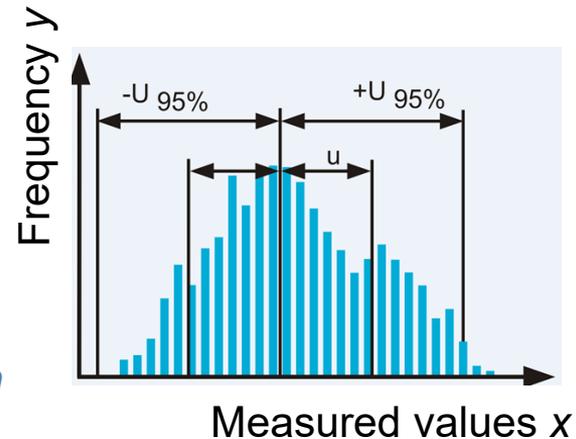
Thermally induced geometric error of CMM

Thermally induced deformation of gear ring

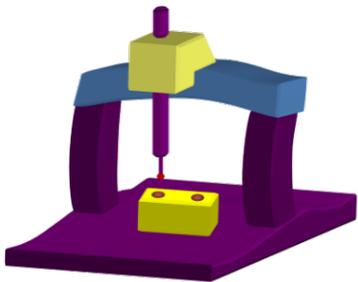
Gravitationally induced deformation of gear ring



Investigation and Characterization



Geometric error of CMM



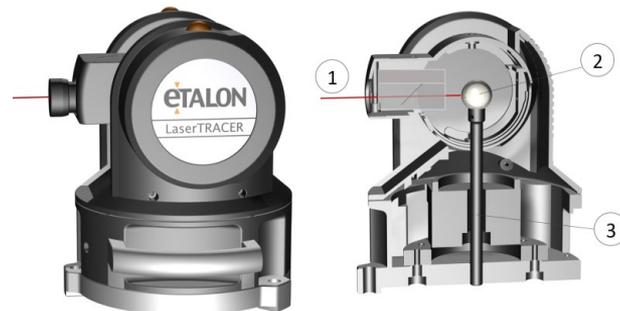
Geometric error of CMM



- Measurement Volume: 5 m x 4 m x 2 m
- Maximal diagonal: 6.7 m
- 66 % of max. diagonal: 4.5 m

Step gauge
Ball plate

- Interferometric distance measuring system:
 - LaserTracer
 - Software tool for acquisition and evaluation

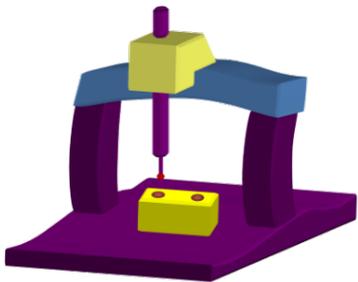


- (1) Measurement beam with nanometer resolution / Messstrahl mit Nanometer-Auflösung
- (2) Reference sphere with form errors < 50 nm / Referenzkugel mit Formabweichungen < 50 nm
- (3) Low thermal coefficient material stem / Halterung aus Material mit geringer Wärmedehnung

source: etalon-gmbh.com

National Metrology Institute

Geometric error of CMM



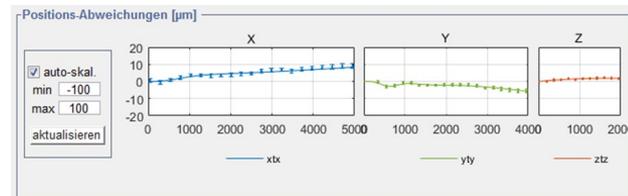
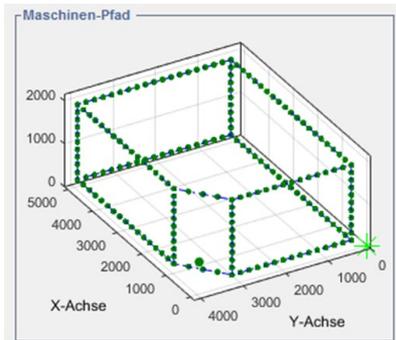
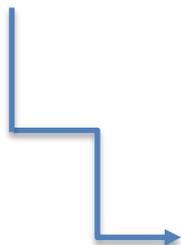
Geometric error of CMM

xml-file for VCMM ✓

Evaluation of 21 geometric errors (full rigid body)

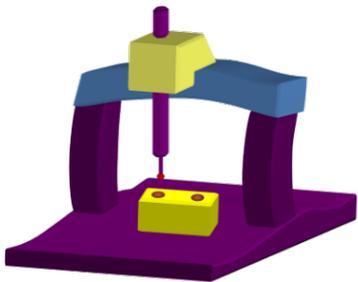
Unsicherheiten (k=2) der parametrischen Fehler

Name	Ergebnis	U (max)	Einheit
xtx	8.3	1.2	µm
xty	6.5	0.8	µm
xtz	2.7	1.1	µm
ytx	0.9	0.8	µm
yty	5.8	0.9	µm
ytz	7.1	0.9	µm
ztx	1.1	0.5	µm
zty	1.3	0.4	µm
ztz	0.1	0.7	µm
xrx	3.5	0.4	µrad
xry	4.3	0.6	µrad
xrz	1.9	0.4	µrad
yrx	2.3	0.5	µrad
yry	0.4	0.6	µrad
yrz	3.8	2.8	µrad
zrx	5.1	4.9	µrad
zry	7.6	3.6	µrad
zrz	2.2	1.1	µrad
xwy	-1.8	0.2	µrad
xwz	-0.8	0.3	µrad
ywz	0.5	0.2	µrad

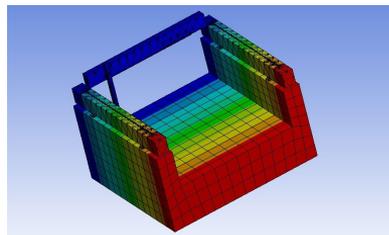


Strategy optimization and traceable measurements

Relevant influences



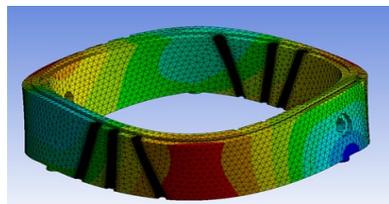
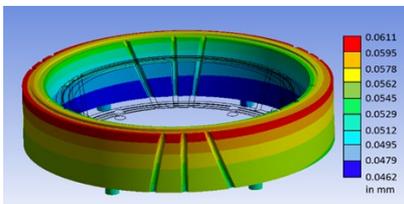
Geometric error of CMM ✓



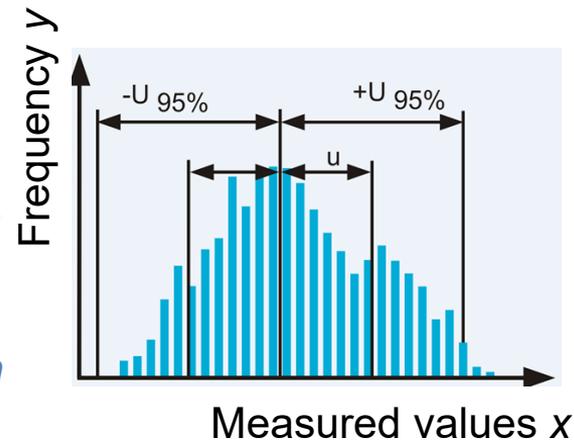
Thermally induced geometric error of CMM

Thermally induced deformation of gear ring

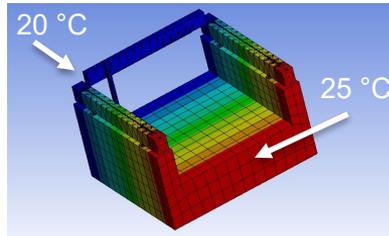
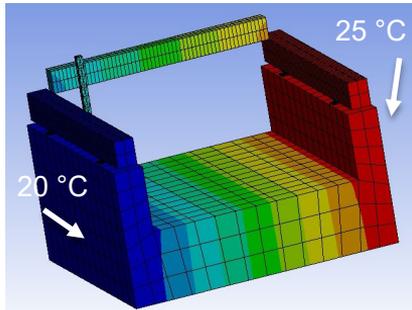
Gravitationally induced deformation of gear ring



Investigation and Characterization

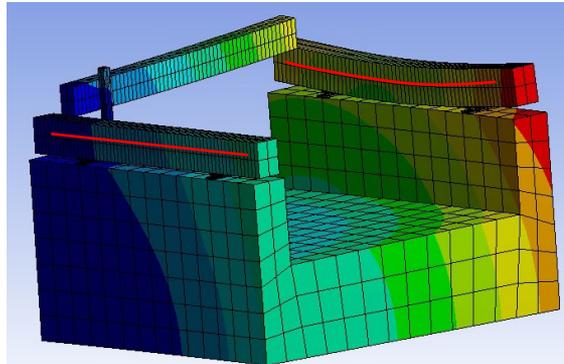
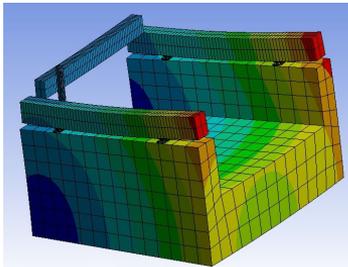


Thermally induced geometric error of CMM



Thermally induced geometric error of CMM

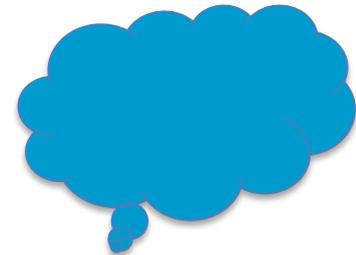
Simulations for identification of affected geometric errors



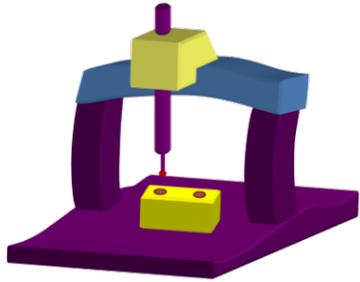
xml-file for VCMM 



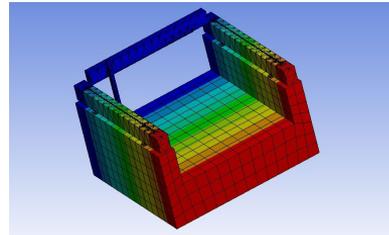
Modelling the impact on measurement uncertainties



Relevant influences



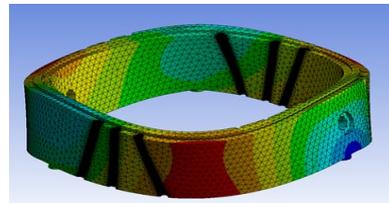
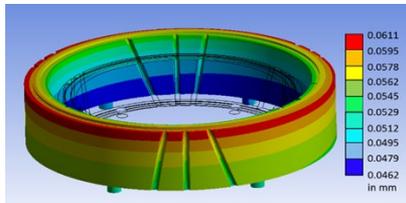
Geometric error of CMM ✓



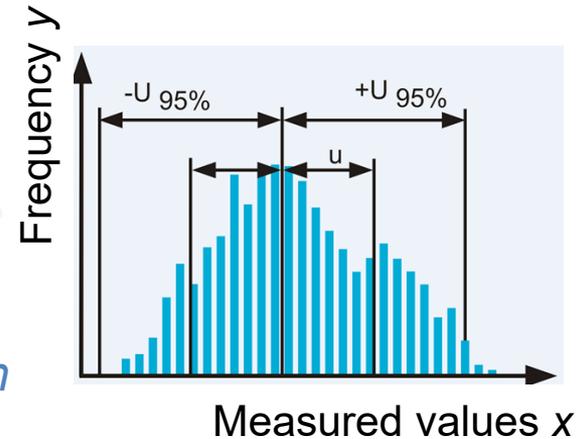
Thermally induced geometric error of CMM ✂

Thermally induced deformation of gear ring

Gravitationally induced deformation of gear ring



Investigation and Characterization

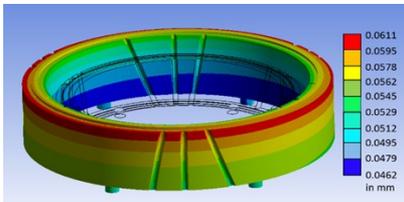


Thermally induced deformation of gear ring

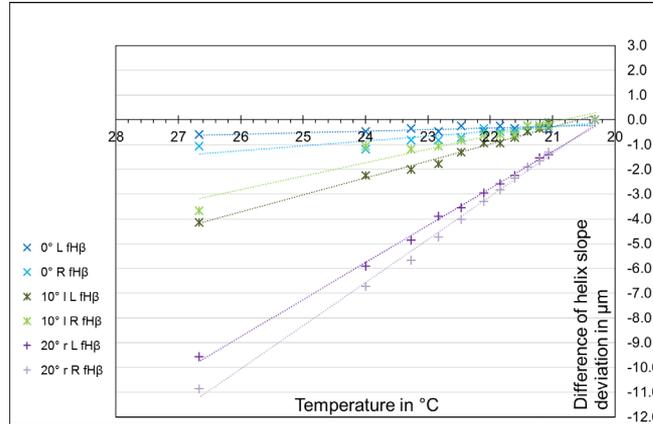
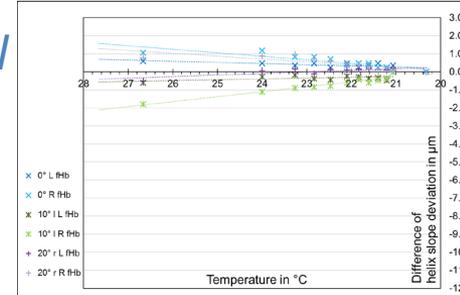
Simulations and traceable measurements of thermally induced deformation



Thermally induced deformation of gear ring



Mathematical correction if possible



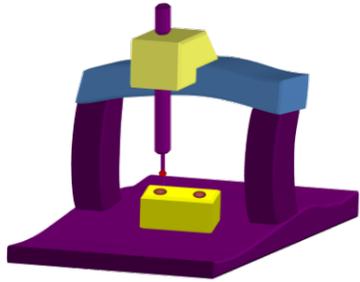
$$f'_{H\alpha} = L_{AE} \cdot \alpha \cdot \Delta T$$

$$f'_{H\beta} = b \cdot \tan \beta_b \cdot \left(\frac{1}{\lambda} - 1 \right)$$

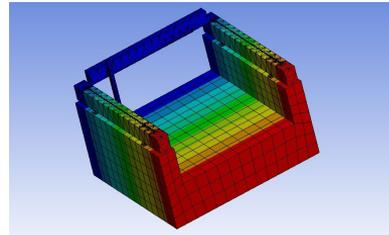
Modelling the impact on measurement uncertainties

xml-file for VCMM ✓

Relevant influences



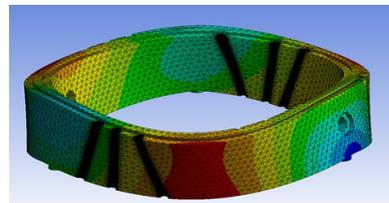
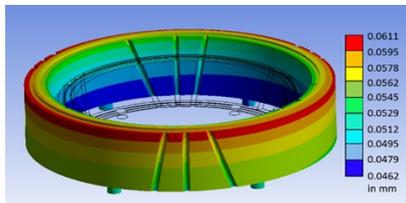
Geometric error of CMM ✓



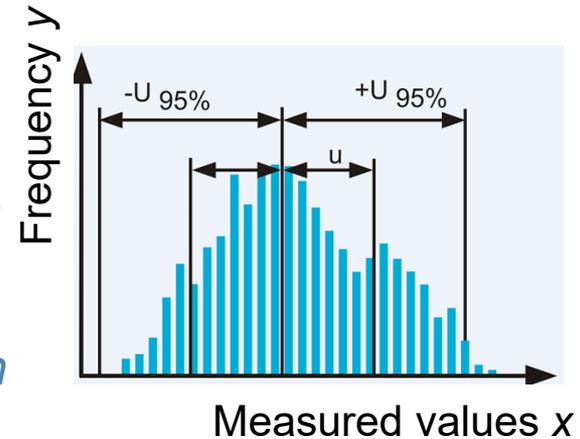
Thermally induced geometric error of CMM

Thermally induced deformation of gear ring ✓

Gravitationally induced deformation of gear ring



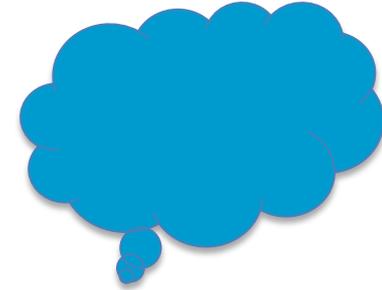
Investigation and Characterization



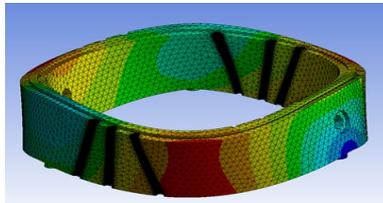
Gravitationally induced deformation of gear ring

Simulations and traceable measurements of gravitationally induced deformation

Modelling the impact on measurement uncertainties

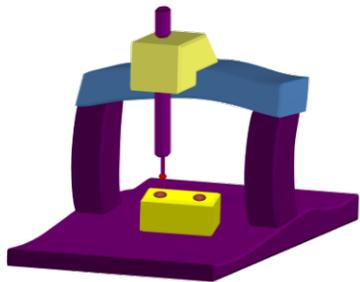


Gravitationally induced deformation of gear ring

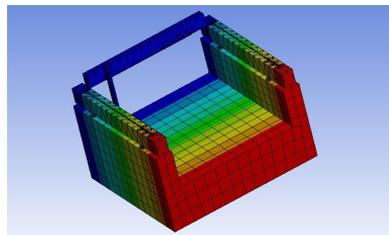


xml-file for VCMM

Summary



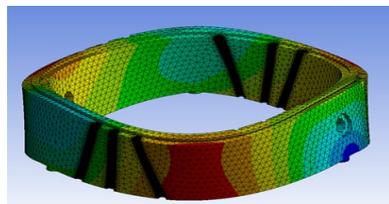
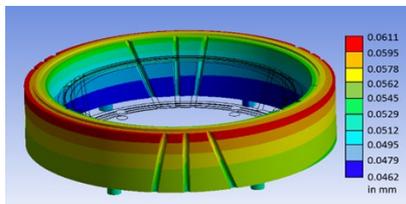
Geometric error of CMM ✓



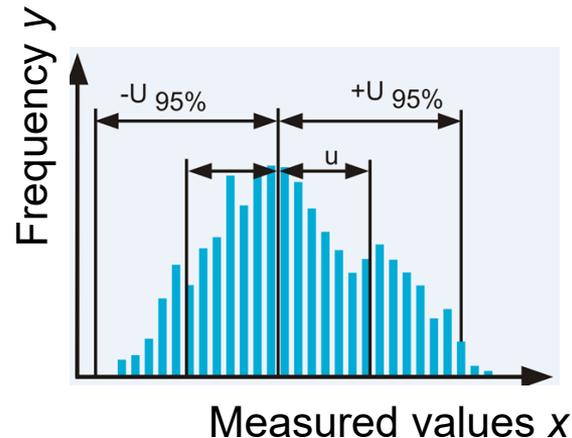
Thermally induced geometric error of CMM

Thermally induced deformation of gear ring ✓

Gravitationally induced deformation of gear ring

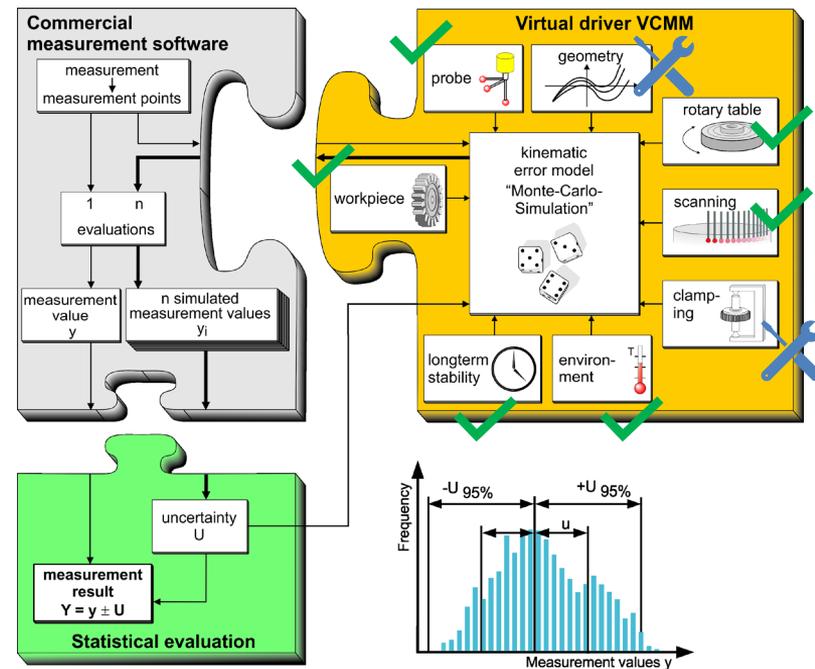


Investigation and Characterization



Outlook

- Characterization for specific influences of large-scaled tasks will be integrated in VCOMM software tool
- Important step to close the traceability chain for large-scaled metrology
- Identify uncertainty contribution of the measurement process to optimize
- Helpful for matching measurement uncertainty with manufacturing tolerances





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Status: 11/19