



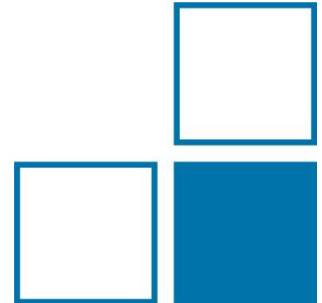
Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Traceable measurements of large gears for wind energy systems

1st 3D Metrology Conference - 3DMC

November 22-24, 2016, Aachen

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Felix Balzer (Hexagon)



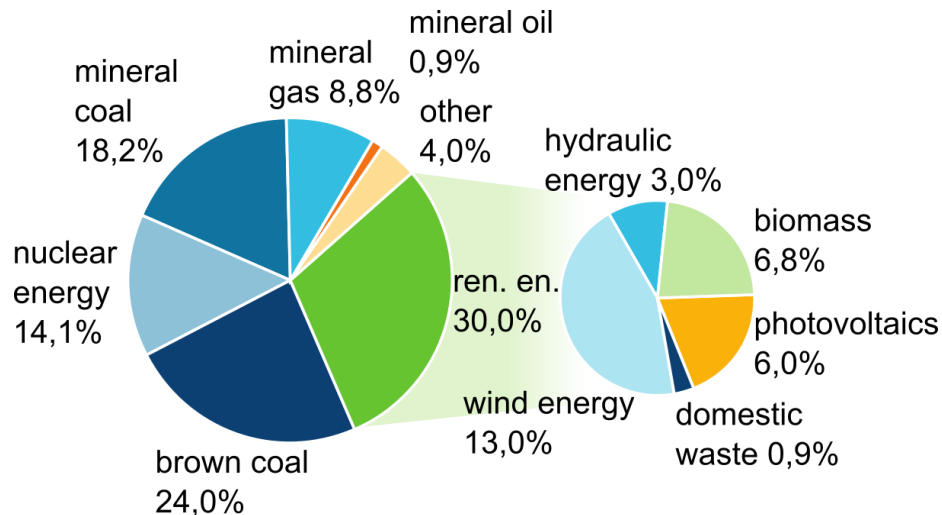
- Introduction
- Large gear measurement standards for industry
- Mobile multilateration measurement system for shop floor calibrations
- Optical measurements of large gears
- Competence Centre for Wind Energy Systems at PTB
- Conclusion and outlook

Ambitious aim for 2035: >50% of energy production in Germany out of renewable sources!



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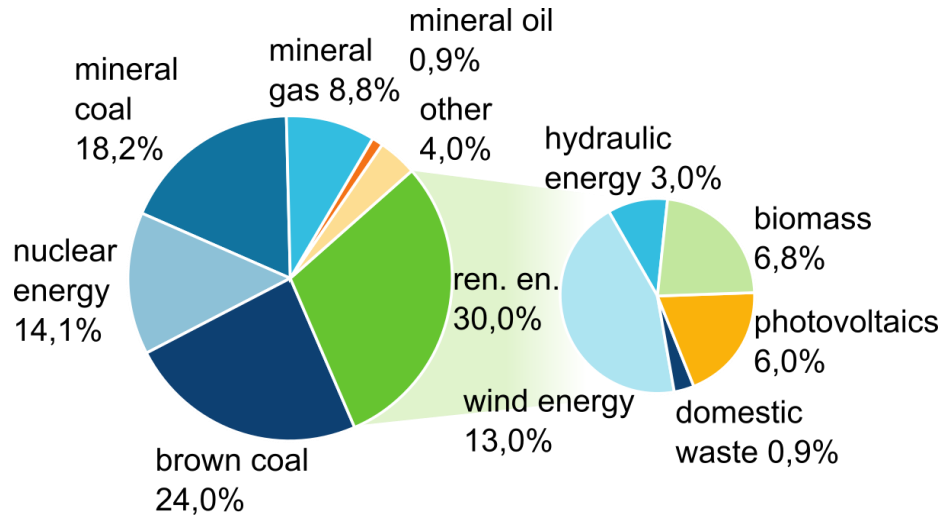
Energy mix in Germany (2015)



Source: BMWi

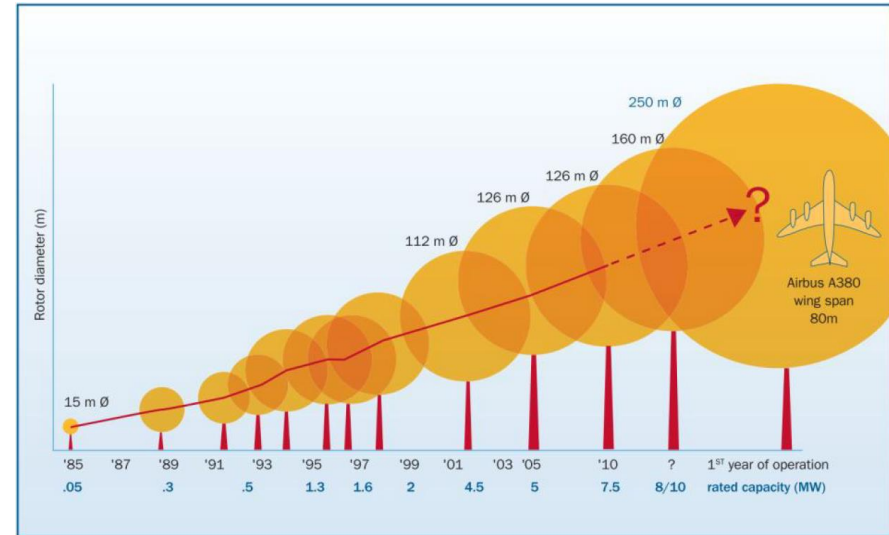
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Energy mix in Germany (2015)



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Evolution of Wind Energy Systems



Source: UpWind Report; European Wind Energy Association, Brussels, 2011

- However: Failure rate of Wind Energy Systems is much too high
- Gearbox errors lead to expensive downtimes
- Traceable metrology is needed to reliably control the manufacturing process
- Workpiece-like measurement standards act as interface to industry



Source: awordaboutwind.com

Large gear measurement standards



- 2010: first large involute gear measurement standard
- Represents cut-out gear segment (\varnothing 1 m)
 - Design allows calibration on established 3D-CMM at PTB
- Embodies three different external gears
- Counter mass for use on rotary table is provided
- 20 sensors for temperature monitoring
- Gold coating against influence of thermal radiation
- Workpiece-like design
- Three spheres for statically determined support

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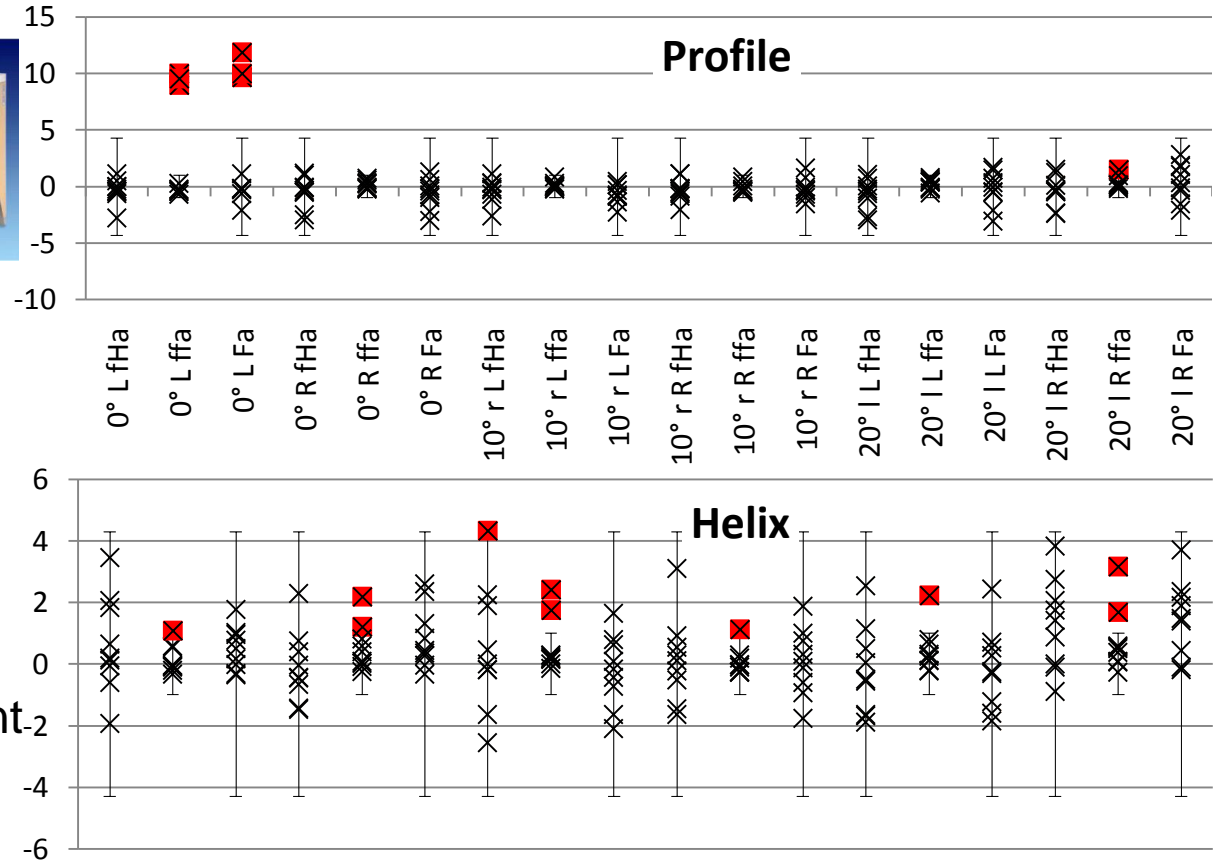
- Large involute gear ring measurement standard
- Outside diameter 2 m / inner diameter 1.7 m
- Internal and external gear type
- Embodies 3 sets of three different helix angles for both gear types
- Weight of 2700 kg
- 12 sensors for temperature monitoring
- special base frame to guarantee reproducible bending

Large gear segment standard

- 2012 -2014: national comparison for large involute gear artifact



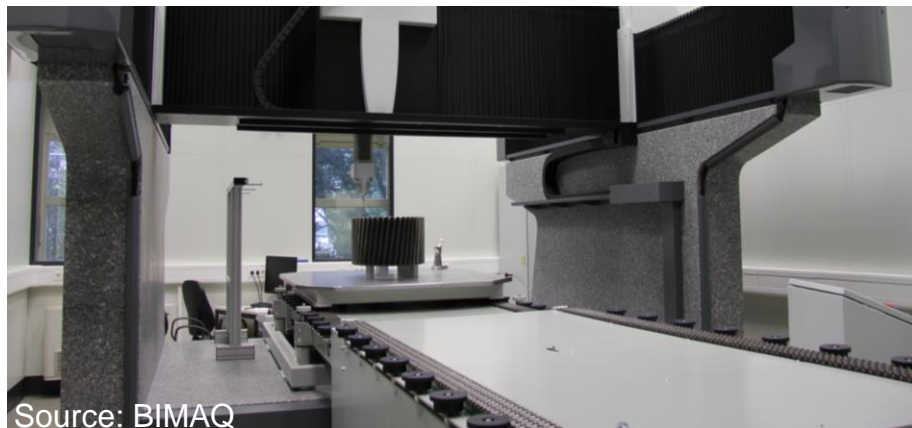
- 9 partners from different branches participated (research institutes, calibration laboratories, manufacturers of drivetrain components, CMM producers)
- different measuring machines and measurement concepts among partners



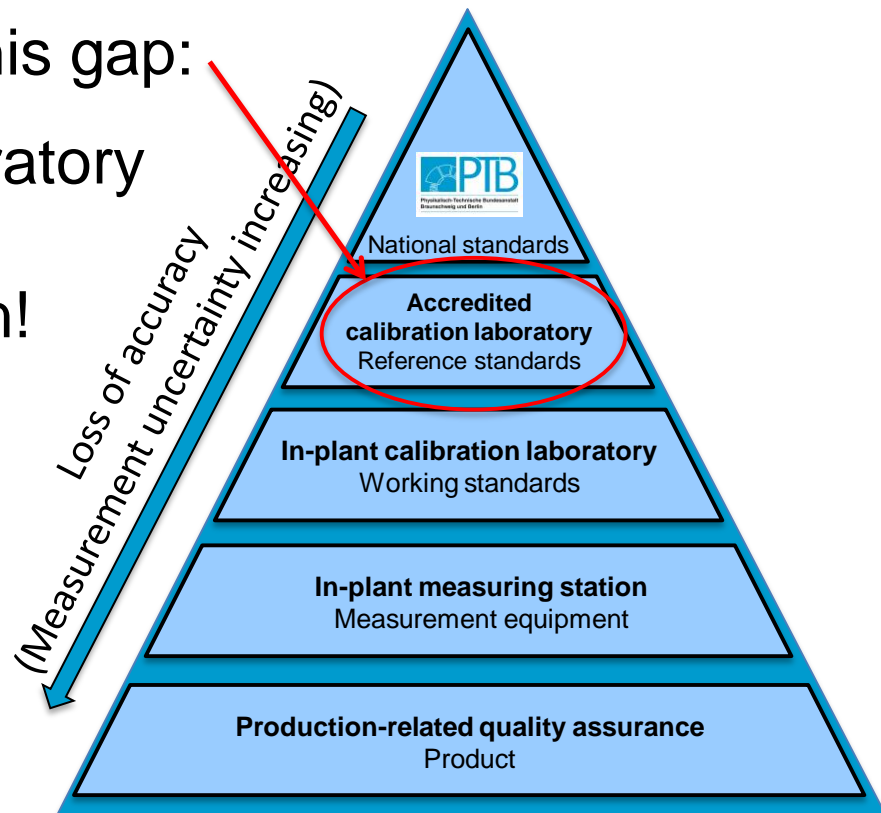
Large gear ring standard



shall be used to fill this gap:
First calibration laboratory
for large gears to be
accredited in Bremen!



Source: BIMAQ



Mobile multilateration measurement system

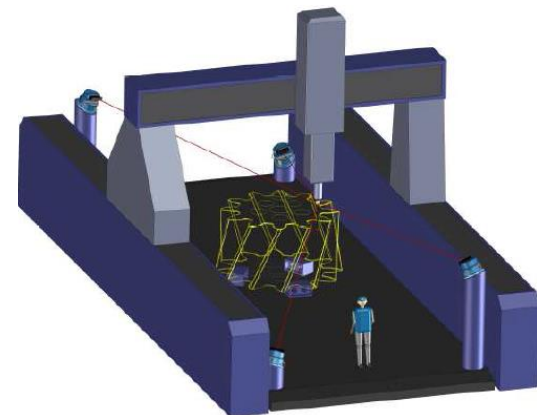
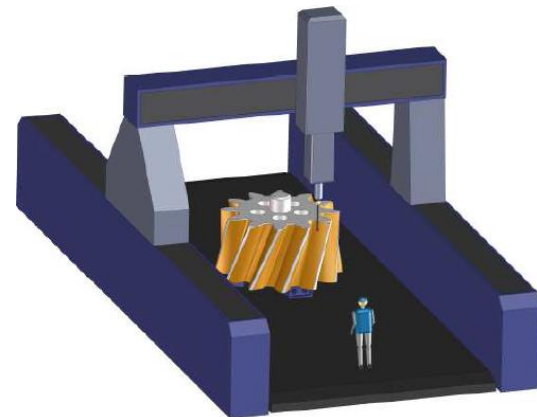


M3D3-measurement is done in two steps

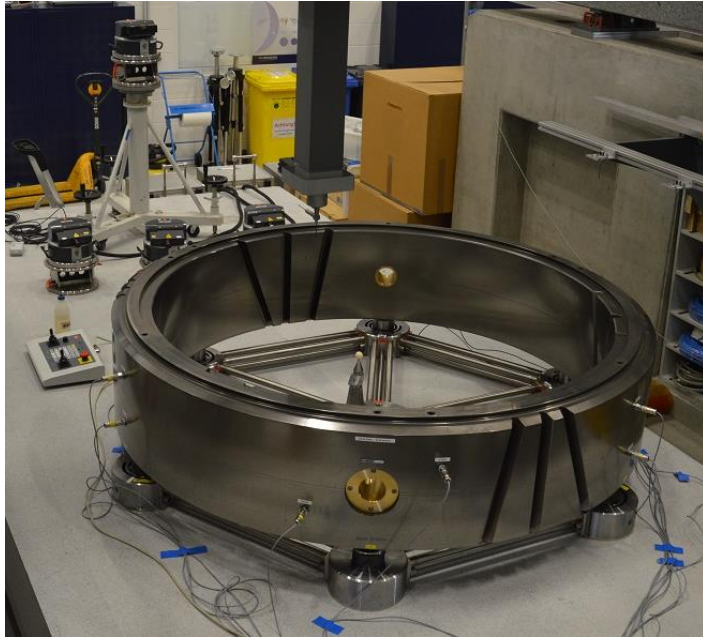
1. Workpiece is measured in tactile manner on CMM
2. Workpiece is removed from measurement volume, stylus is replaced by retro-reflector, CMM replays all probing points from step 1 and positions are measured by (at least) 4 LaserTracers by multilateration

Evaluation

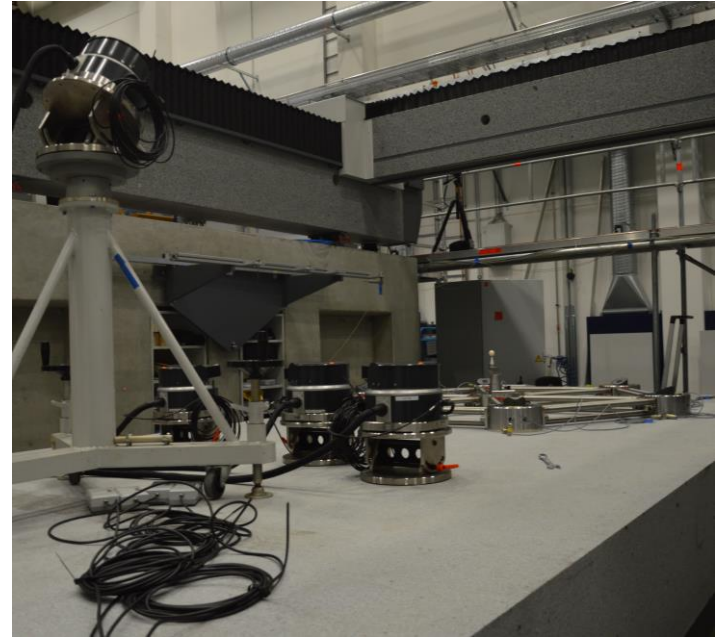
3. Local error vectors are calculated based on step 2
4. Error vectors are used to correct measurement points from step 1
5. Corrected point cloud is retransferred to the measurement software for the measurement task specific evaluation



Mobile multilateration measurement system



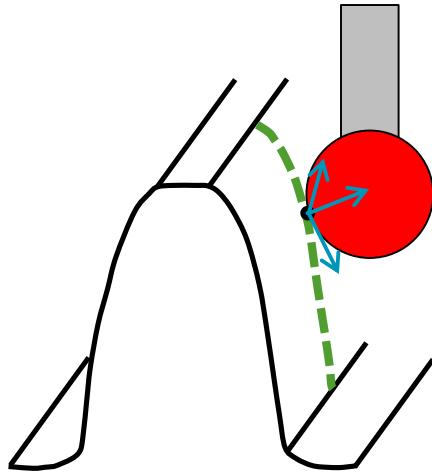
Step I



Step II

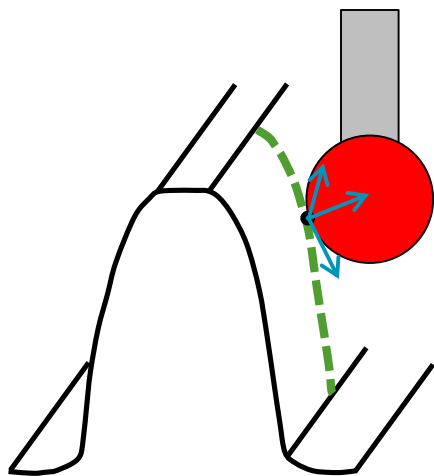
Measurement uncertainties for all gear parameters $\leq 3.4 \mu\text{m}$

- Classical measurement technique: 3D tactile probing



Optical measurements of large gears

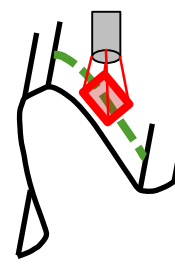
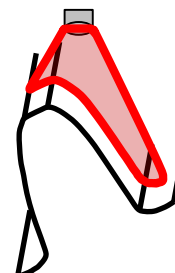
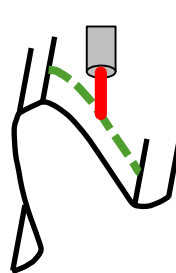
- Classical measurement technique: 3D tactile probing
- Neo-classical measurement technique: optical sensors



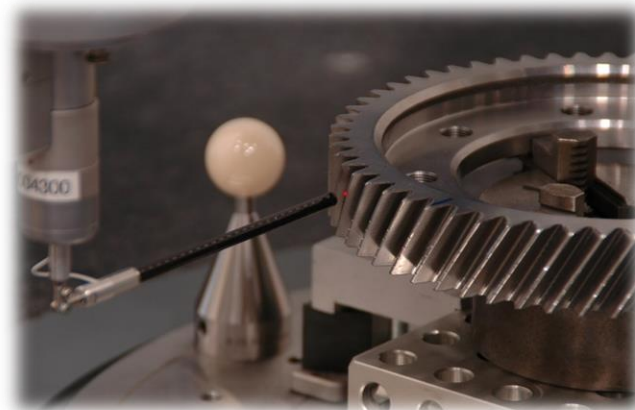
Point sensor
(1D)

Line sensor
(2D)

Areal sensor
(2.5D)

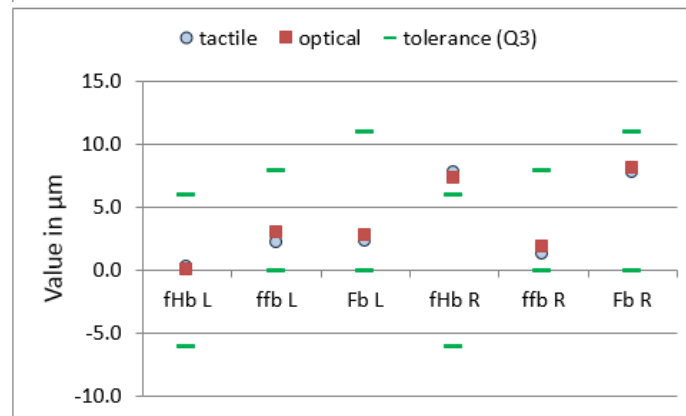
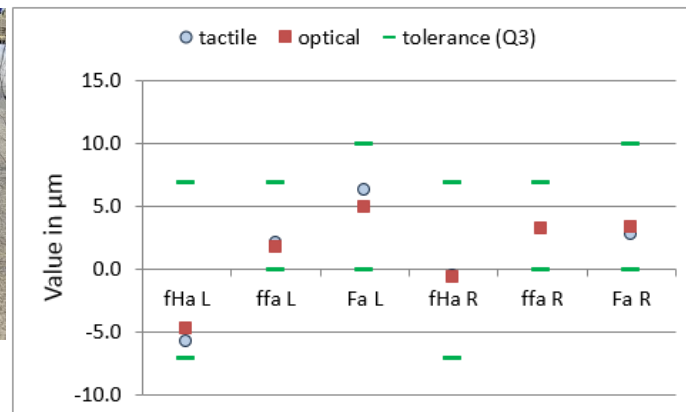


- First tests run with HP-O sensor (Hexagon)
- High precise interferometric distance-sensor with sub-micrometer resolution
- Sensor measures well on all metallic surfaces with opaque scattering ($R_z > 0.3 \mu\text{m}$)
- Flexible usage due to 3D joint and various optics

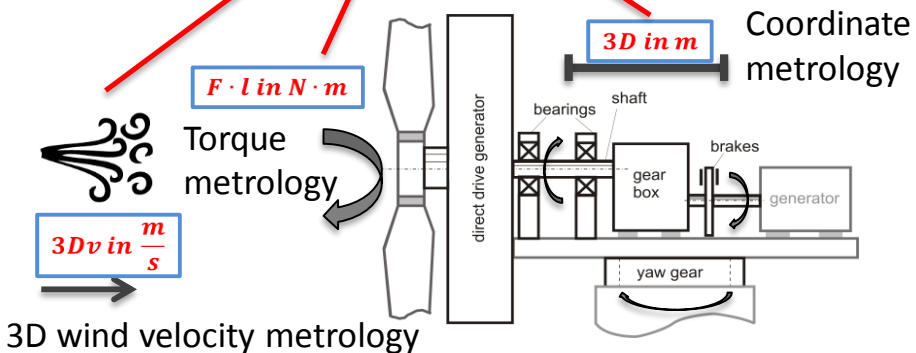
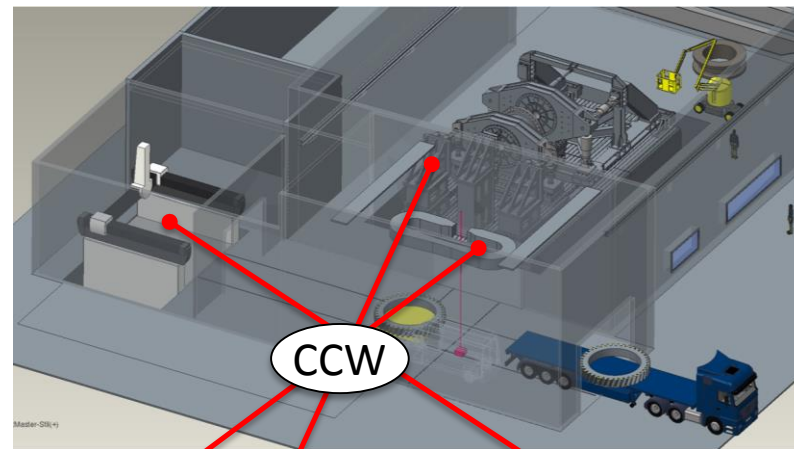


Comparison tactile vs. HP-O

- Tests run on external 10°r of large ring gear
- Scanning mode
 - tactile: $v = 10$ mm/s, no filter
 - optical: $v = 50$ mm/s, standard filter according to ISO 1328
- 5 repetition measurements



Competence Centre WIND at PTB



- Research project (2016 – 2020) funded by BMWi with 10^7 €
- Large CMM (5 m x 4 m x 2 m) to be installed in 2017
- Enhancement of VCMM focused on uncertainty contributors relevant for large parts
- Implementation of M3D3-System
- Extension of PTB's calibration and measurement capabilities
- Support of German Accreditation Body (DAkkS) and establishment of new calibration laboratories

- Reliable operation of Wind Energy Systems needs traceable metrology for large gears
- PTB developed worldwide unique large gear measurement standards
- Competence Centre Wind is currently being built and large CMM will be put into operation end of 2017
- Large gear calibrations (up to $d = 4$ m) will be possible at PTB from on 2018

Thanks!



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