Metrological Competence Center for Windenergy

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Abstract. The Competence Center for Windenergy of the Physikalisch-Technische Bundesanstalt provides a worldwide unique metrological infrastructure for high level calibrations of mechanical components for wind energy and wind lidar systems. The focus is on three measuring devices. First, a large coordinate measuring machine with a measuring volume of 5 m x 4 m x 2 m for drive train components, second, a wind tunnel for the calibration of mobile wind lidar systems, and third, a torque standard measuring machine for the calibration of torque transducers with a maximum load of 5 MN m, which can be expanded to 20 MN m. The first part was completed with the inauguration of the Euler I building in February 2018. It functions as both, a large coordinate measuring machine and a wind tunnel. The standard torque measuring device is expected to be implemented in 2020 after finishing the Euler II building. The five-year project started in 2016. The cost of new buildings, measuring machines and developments is about 15 million €. The project is funded by the German Federal Ministry for Economic Affairs and Energy via the project's executing organization in Jülich.

1. Introduction

The nuclear disaster at the Daiichi nuclear power plant in Fukushima, Japan, triggered a radical turnaround of Germany’s energy policy in March 2011. As a result of this catastrophe, the German Bundestag passed its thirteenth law amending the Atomic Energy Act on June 30, 2011. It determines to end the operation of all nuclear power plants in Germany by 2022 [1]. The Physikalisch-Technische Bundesanstalt (PTB) reacts directly to an energy concept called "Energy for Germany - Metrology for the Energy Sector" [2]. It suggests the establishment of a metrological infrastructure needed by industry in order to improve the energy efficiency of existing power plants and to enhance the quality of new production processes. One focus was given on renewable green energy systems such as wind energy systems (WES). At that time, decision-makers from leading companies together with representatives from PTB met to form the framework requirements for a Competence Center for Windenergy (CCW) addressing three focal points:

- calibration of large 3D components of WES drive train components, with focus on the calibration of large gear standards with diameters of up to 4 m, for example,
- portable systems for the measurement of 3D wind speed vectors enabling the traceable determination of wind profiles up to a height of 250 m
- calibration of torque transducers allowing the transmission up to 5 MN m

Up to the present, the metrological infrastructure in all these areas has been nonexistent in National Metrological Institutes (NMIs).
2. Dimensional calibration of drivetrain components

Components of gear driven WES as well as direct or hybrid types require measurement uncertainties down to some micrometers. For ensuring this accuracy, calibrated measurement standards for these components, such as gears, stator- and rotor-parts, bearing rings, shafts or brake-discs are needed. With the new large coordinate measuring machine (CMM) featuring a measurement volume of 5 m x 4 m x 2 m the PTB is able to provide these calibrations in future (figure 1).

![Figure 1 Coordinate measuring machine](image)

The installed Leitz PMM-G is designed as a gantry bridge type CMM. It is equipped with tactile and optical sensors: the “Precitec sensor” as a chromatic confocal sensor and the H-PO sensor based on frequency-modulated interferometric optical distance measurements. All sensors can be operated in both, single probing as well as in high speed scanning mode. Component parts of maximum 15 t load can be shifted from an acclimatization room onto the machine bed via pallets that are moved on a trail system. It is also possible to integrate a portable rotary table into the CMM, if measurements of rotatory parts have to be performed. A selection of main specifications according ISO 10360 is given in Table 1.

| Parameter | Maximum permissible error (MPE) |
|-----------|--------------------------------|
| Volumetric length measuring error $E_0$, $E_{150}$ | $E_0$, $E_{150} = 3.3 \mu m + L / 400$ |
| Repeatability range $R_0$ | $R_0 = 1.7 \mu m$ |
| Single stylus form error, scanning THP | THP = 3.3 $\mu m / 64$ s |
| Single stylus form error $P_{FTU}$ | $P_{FTU} = 2.4 \mu m$ |
| Form measurement error RONt | RONt = 3.0 $\mu m$ |

In order to improve the measurement uncertainty, a mobile multilateration measuring system for three-dimensional measurements (M3D3) developed by PTB [3] will be integrated inside the measurement volume of the CMM as metrological frame. The M3D3-procedure is performed in two steps. In a first step the workpiece is measured in a tactile manner on the CMM. Then the workpiece is removed from the measurement volume and at least four parallel tracking laser interferometers are automatically following a retroreflector mounted instead of a stylus tip. Based on a multilateration algorithm all 3D-positions are calculated from the measured interferometric displacements almost avoiding Abbe errors. For each measurement point the local error vector is evaluated as the difference between the indicated mover position by the CMM and the position measured with M3D3. This is used to correct the original measurement data from the first step point by point.

3. Wind tunnel facility for the calibration of wind lidar systems

A wind tunnel at the CCW offers calibration capabilities for the novel bistatic PTB wind lidar device that are unparalleled throughout the world [4]. The lidar device will be used as a reference standard for
ground based wind vector measurements in heights up to 250 m. This enables the calibration of customary remote sensing devices. The wind tunnel was built in the Göttinger type design [5]. It allows to generate homogeneous wind fields with speeds in the range from 1 m/s to 30 m/s in a test section with a cross section of 0.5 m² and a length of 0.8 m. The expected measurement uncertainty \(U(k=2)\) for the representation of the wind speed is below 0.2%. A calibrated Laser Doppler Anemometer (LDA) is used as reference standard to ensure well defined wind conditions inside the test section at the measurement position of the bistatic PTB wind lidar. The setup of the test system is shown in Figure 2a.

A walkable platform is carrying the wind tunnel in a height of 8 m from ground level. Inside a measurement room of 17.9 m in length, 10.0 m in width, and 9.5 m in height, the system can be operated throughout the year independent of any weather conditions (figure 2 left). The mobile bistatic wind lidar system can be placed directly below the wind tunnel system. The distance to the test section is sufficient to calibrate the PTB-lidar against the LDA used as reference standard (figure 2 right). Thus the LDA is used in the CCW wind tunnel facility to verify and validate PTB’s bistatic wind lidar as transfer standard and henceforth as primary standard for the use at wind test sites.

4. Torque measurement standard for the calibration of torque transducers

A novel torque measurement standard (TMS) for the calibration of torque transducers with a maximum moment of 5 MN·m was designed by PTB [6]. In addition to torque, the TMS is also able to induce bending moments up to 3 MN·m, axial forces up to 2 MN and shearing forces up to 1 MN·m to torque transducers under test. Usually, the calibration is carried out in a static mode. For dynamic investigations, the static moment can be superimposed by an additional dynamic moment of 600 kN·m with a frequency up to 3 Hz. Figure 3 shows the TMS which is of 17 m in length and 9 m in width. The total mass amounts to 1650 t.

The TMS operates according to the reference principle. Therefore, all moments and forces are generated and measured separately and independently on different locations. The components of this worldwide unique machine can be separated in three functional components: an actuator frame, a measuring frame, and the machine foundation.

The forces are generated via hydraulic cylinders mounted in the actuator frame. The 6-m lever will induce the required moments and forces which are directly transmitted to the torque transducers and to the measurement frame. The torque around the axis of the transducer under test is measured by means of a force lever system. Besides the torque, the bending moments perpendicular to the axis of the transducer under test and the forces along this axis will also be measured. The TMS foundation performs active vibration isolation and fixes the parts of the machine's frame. Its very high stiffness must be considered an advantage for the adjustment and calibration of the torque transducers, since the
machine may not exhibit any substantial creep phenomena after the load has been applied. The resonance frequency of the foundation can be adapted to the excitation frequency.

Figure 3 Sketch of the 5 MN∙m torque measurement standard

Completion of the machine is planned for 2019 with its commissioning envisaged by 2020. The fundament of the machine, its level and frames are dimensioned in such a way that the rotatory moment can later be extended up to 20 MN∙m.

5. Summary
The wind competence center of the Physikalisch-Technische Bundesanstalt enables the calibration of geometrical parts as well as wind lidar systems at its lowest possible measurement uncertainty. With completion of the Euler I building, the first two calibration systems went into operation in the beginning of 2018. The building contains a coordinate measuring machine tuned up by tracking laser interferometer enabling drive train components to be calibrated inside a measurement volume of 5 m x 4 m x 2 m and a wind tunnel allowing the calibration of mobile wind lidar systems. In 2020 the Euler II building will be finished. Then a torque standard measurement device will be operated in order to calibrate torque transducers with a moment up to 5 MN∙m. In future this system shall be extended to 20 MN∙m.

6. Acknowledgement
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7. References
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