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NEW PERSPECTIVES FOR MN·m TORQUE MEASUREMENT AT PTB

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Abstract: To verify all technical aspects of wind turbines, more and more nacelle test benches have come into operation. One crucial parameter of such test benches is the torque initiated in the nacelles, which amounts to several MN·m. To date, no calibration traceable to national standards has been performed on such test benches. An EMPIR program dedicated to MN·m torque measurements is currently in progress in order to solve several issues associated with torque calibration for nacelle test benches. Concurrently, PTB has started to construct a competence center for wind energy to provide metrological support to the wind industry.

Keywords: torque, calibration, transfer standard, wind energy, nacelle test bench

1. INTRODUCTION

The percentage of renewable energies used to produce electricity is increasing dramatically. For instance, in 2016, 32.5 % of all energy generated in Germany came from renewable energy sources, of which wind energy amounted to 44.3 %. The German government intends to increase the percentage of renewable energy used to generate power to 40-45 % by 2025, whereas wind energy likely to provide the greatest contribution to this planned expansion. Furthermore, the performance of wind generators is likely to significantly increase during this period, driven by an increase in the height, rotor diameter and output power of individual wind turbines, as seen in Fig. 1, taken from [1].

Because the reliability of wind turbines to produce energy strongly depends on their technical reliability, several nacelle test benches have been established to ensure this technical reliability. One crucial parameter of such nacelles is the torque load initiated according to the strength of the wind field. In nacelle test benches, a special motor (often called a prime mover) is used to create the torque instead of wind power. Often, an additional device is mounted between the motor and the nacelle to create axial forces, as well as parasitic bending forces and moments, that act on the drive train. The torque M is directly related to the electrical power P_{el} and depends on the rotational speed n.

Tab. 1 shows an example of two points of operation. An inquest about existing nacelle test benches, which was done in the framework of the EMPIR project "Torque in the MN·m range", has resulted in 10 test benches in Europe with a power from 1-18 MW. Of these, the Vestas test bench has the greatest torque to date; 22.5 MN·m with a power of 18 MW.

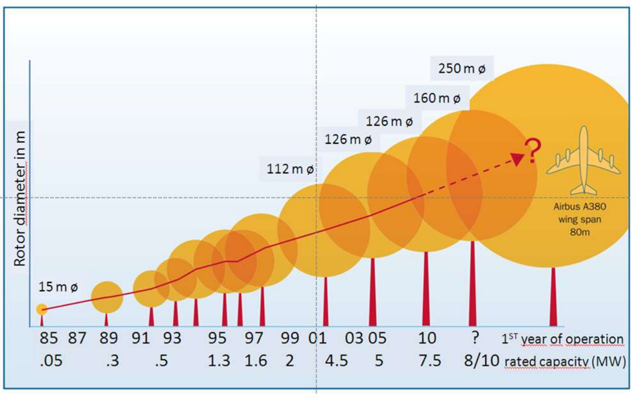

Fig. 1. Development of the size of wind turbines [1]. The horizontal axis shows in the first line the year where this kind of wind turbines started to operate. The second line shows the nominal power of the turbines.

$$M = \frac{P_{el}}{2\pi \cdot n} \tag{1}$$

As shown in equation 1, the torque can be determined by means of an electrical power and a rotational speed measurement. Nevertheless, because this measurement type results in relative uncertainties of several percent, a more precise mechanical measurement of the torque is necessary.

Electrical power in MW	Revolution speed in rpm	Torque in MN·m
5	14	3.4
10	9	10.6

Table 1. Examples of the relation between electrical power and torque.

Special torque transducers have been built to measure the torque in the drive train. Unfortunately, not all of these transducers are calibrated in the MN·m range, due to the lack of a calibration facility. Sometimes, they are calibrated partially and extrapolated (e.g. via finite element calculations) to the nominal torque.

Chapter 2 will introduce the EMPIR project titled "Torque in the MN·m range"; Chapter 3 will devote attention to WP 2 of this EMPIR project, which deals with the metrological characterization of a 5 MN·m torque transducer. Chapter 4 will introduce the new Competence Center for Wind Energy

(CCW) at PTB, devoting special attention to the planned 5 MN·m standard torque machine.

2. EMPIR PROJECT FOR MN·m TORQUE MEASUREMENT

In October 2014, an EMPIR project titled “Torque in the MN·m range” was launched [5]. The main purpose of the project is to precisely determine the efficiency of nacelles and their single components (e.g. gear boxes). The project was conceived to establish a solid technical basis for the development and optimization of nacelle testing technology and to simplify procedures for the certification of the nacelles. An additional purpose of the project is to ensure traceability of the torque measurement in nacelle test benches.

The project is subdivided into seven WPs.

WP1 provides an overview of the conditions and measurement systems of existing test benches. This overview primarily focuses on the existing torque measurement principles and calibration procedures. In addition, WP1 compiles all relevant technical parameters and boundary conditions of all existing nacelle test benches, as listed in Tab. 2. Finally, this WP presents the main objectives of the different investigations that have been conducted on these nacelle test benches.

In WP 2, a torque transducer is characterized in order to become a torque transfer standard that provides traceability for nacelle test benches. Here, one important aspect is the development of a procedure to extrapolate data to nominal torque ranges that cannot be calibrated [2]. This will be realized by a combination of partial calibrations in the PTB 1.1 MN·m standard torque machine [3], by mathematical extrapolations and by FEM simulations.

The focus of WP3 is the investigation of multi-component torque transducers. Even nacelle test benches involve several perturbations that generated from bending moments, lateral forces and vibrations. The task of an ideal transfer standard would be to incorporate these influences into the calibration; as a minimum, this will allow the cross-talk effects from these influences to be quantified. Experimentally, these can be investigated in the kN·m range by means of the PTB Hexapod Multi-Component Machine [4]. This machine can realize side forces of up to 10 kN and bending moments of up to 1 kN·m, which can be initiated simultaneously in the device under test. As an additional component of this WP, FEA simulations are conducted to support the interpretation of the measurement results.

In WP4, force lever systems are theoretically investigated to determine their usability for a traceable calibration of nacelle test benches. In this context, a force lever system is a torque transducer whose interior structure is composed of several force transducers. These force transducers act on levers that extend from the center of the torque transducer. One important aspect of such systems is the precise geometrical measurement of the levers. The force transducers can be traced back to national force standard machines.

In WP5, a general calibration procedure is worked out for nacelle test benches that will be tested on the test bench of RWTH Aachen. The transducer characterized in WP2 will be mounted on the test bench and used to calibrate the internal test bench torque transducer.

Finally, like in every EMPIR project, WP6 presents the impact and WP7 oversees the management and coordination of this project.

3. METROLOGICAL CHARACTERISATION OF A 5 MN·m TORQUE TRANSDUCER

To realize WP2 and WP5 of this EMPIR project, a commercial torque transducer with a nominal range of 5 MN·m was bought. (see Fig. 2). The image in Fig. 2 depicts the transducer together with two DMP41 bridge amplifiers. The transducer is equipped with two independent torque channels, two channels for transverse forces, two channels for bending moments and two channels for axial forces. These additional channels allow an investigation of the effect of multi-component loading on the measurement of torque. Cross-talk effects in multicomponent loading are studied to describe effects on the torque measurements that occur in large nacelle test benches. Finally, a calibration procedure for large nacelle test benches can be tested with this new transducer. The calibration procedure will enable the traceability of torque loads of up to 5 MN·m and will include an uncertainty model that considers cross-talk effects.

Fig. 2. 5 MN·m torque transducer together with two DMP41 bridge amplifiers for the readout of the eight channels of the transducer.

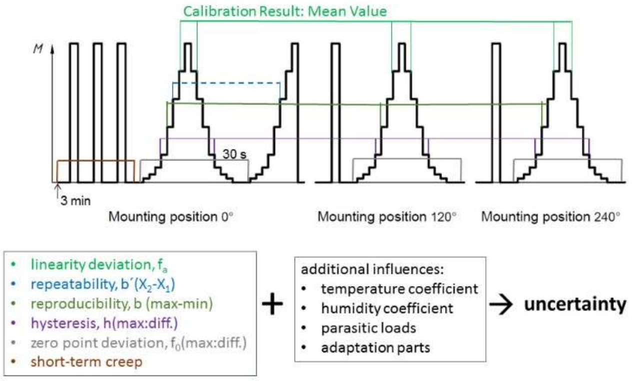

Fig. 4. Calibration procedure according to German standard DIN 51309. Several parameters are indicated that are derived from the calibration data.

Initial calibration measurements were performed with the 5 MN·m torque transducer shown in Fig. 2 in the PTB 1.1 MN·m standard torque calibration machine. Here, the procedure according to the German standard DIN 51309 was applied [6]. Fig. 4 shows the calibration procedure according to this standard. In this procedure, after three preloads, a certain number of upward and downward steps are performed in three mounting positions. At least eight steps are required to determine a linear or polynomial fit. From the data, several characteristic parameters are derived that are used for the determination of the measurement uncertainty as well as for a classification of the torque transducer. The parameters are indicated in Fig. 4 in the calibration procedure. One characteristic result of the calibration is the deviation from the linearity shown in Fig. 5. The curves reflect the relative deviations of the measured values from a fitted straight line; the deviations are related to the measured mean value of the maximum value. The fitted straight line goes through the origin and the mean maximum signal value at the load maximum. During the measurement campaign, partial ranges within the 1.1 MN·m range were also measured. This data will be used in connection with FEM simulations to develop extrapolation procedures.

In addition, the signals from the other six parasitic channels were also recorded. The analysis of these data will provide information about the correlations between the torque and the forces, moments and axial force.

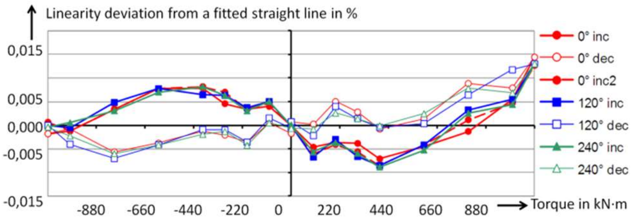

Fig. 5. Linearity deviation from a straight line fitted through the origin at zero. The deviations are related to the measured mean value at maximum load.

4. THE NEW COMPETENCE CENTER FOR WIND ENERGY (CCW) AT PTB

Due to the technical parameters of the current, newly installed wind turbines, the requirement for a metrological characterization of these devices has arisen. As seen in Chapter 3, the calibrations are currently limited to a nominal range of 1.1 MN·m. For this reason, PTB decided to build a special competence center for wind energy (CCW). This concept includes two new buildings called Euler I and Euler II; Euler I will house a new coordinate measuring machine and a wind channel to test LIDAR systems, while Euler II will house a new torque standard calibration machine with a capacity of up to 5 MN·m (with the capability for an upgrade to 20 MN·m).

The coordinate measuring machine will require a mounting space of 5 m x 4 m x 2 m, as this will make it geometrically possible to measure the gear parts of nacelles. The wind channel facility enables a systematic investigation and validation of uncertainty budgets for 3D wind velocity measurements.

Lever length: 3 m		
Mounting space for the transducer under test: 3 m		
Target design for the 5 MN·m machine:		
Torque	5 MN·m	1 MN·m Servocylinder
Bending moment	3 MN·m	0.5 MN·m servocylinder
Axial force	1 MN	
Dynamic	±600 kN·m @ 3 Hz	F_{dyn} = 100 kN
Target design for the 20 MN·m machine:		
Torque	20 MN·m	3.3 MN·m Servocylinder
Bending moment	10 MN·m	1.5 MN·m Servocylinder
Axial force	3 MN	
Dynamic	±600 kN·m @ 3 Hz	F_{dyn} = 100 kN

Table 3. Technical parameters of the new PTB 5 MN·m torque machine.

The design of the new torque calibration machine (see Fig. 6) will be similar to that of the PTB 1.1 MN·m calibration machine, based on a two-lever system: one actor lever and one measuring lever. The forces acting on the actor lever will be generated by two 1 MN servo-hydraulic cylinders.

In addition, the bending moments and axial forces listed in Table 3 can be applied by means of a pair of horizontally aligned servo cylinders. The servo cylinders will also be able to operate dynamically in a frequency range of up to 3 Hz with a dynamic force of ±100 kN. For this reason, the foundation of the machine is mounted on air springs. The pressure of each spring can be individually adjusted to achieve an optimal damping and to avoid resonance frequencies. The measuring lever system includes a pair of force transducers to measure the main force component of the torque, and several spring elements to detect parasitic

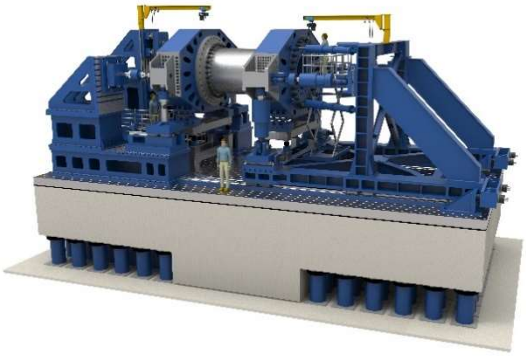

Fig. 6. Design of a new standard torque calibration machine for torques of up to 20 MN·m.

bending forces and moments.

5. CONCLUSIONS

To increase the reliability of wind turbines, extensive technical tests are performed on nacelle test benches. One important aspect of these tests is the torque initiated in the nacelle in the MN·m range. To date, traceable torque calibration in the MN·m range can only be realized by means of the 1.1 MN·m torque standard calibration machine at PTB. One solution for achieving a traceable torque calibration of nacelles is to use torque transfer standards calibrated in standard calibration machines that are suitable for the MN·m range and are traced back to the SI, in combination with extrapolation procedures. Currently, a calibration up to 1.1 MN·m of such transducers is feasible; however, for the above-mentioned torques, special extrapolation procedures must be developed. To overcome the insufficient calibration range, a new machine will be built within PTB's new Competence Center for Wind Energy. This machine will be able to calibrate torques of up to 5 MN·m in the first stage and up to torques of up to 20 MN·m in the second stage.

Acknowledgements

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