Newsletter

Met4Wind

January 2022

Met4Wind (Metrology for enhanced reliability and efficiency of wind energy systems) is a European Research project within the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

Why Met4Wind ?

The mechanical components of Wind Energy Systems (WES) are exposed to the highest loads, with torques of up to 20 MN·m acting on the blades, and these are transmitted to the drivetrain's components. Therefore, the requirements on these parts are high and this often results in tight manufacturing tolerances related to their size and mass. Reliable verification of manufacturing tolerances through accurate measurements is a critical part of quality assurance. This project will improve industrial measurement capabilities for the mechanical parts of WES following the Manufacturing Metrology Roadmap 2020 and it will help to accelerate the energy transition by enhancing the efficiency of WES technology.

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Our objectives

The overall objective of the project is to enhance the reliability and efficiency of WES by ensuring the traceability of the measurements of their mechanical components, thereby improving industrial production processes in order to fulfil the demands of the Manufacturing Metrology Roadmap 2020.

The specific objectives of the project are:

1. To investigate fast optical and multi-sensor measurement methods for roughness, form, and dimensions of mechanical components of WES and to determine the associated uncertainties.
2. To develop improved measurement and evaluation methods for the surfaces of industrial and WES drivetrain components, considering material properties, when appropriate.
3. To develop a digital twin (DT) of drivetrain and turbine blades to predict the degradation in the turbine's efficiency.
4. To evaluate and improve the accuracy of machine tool measuring stations for fast and flexible in-line metrology operating in harsh environments

Highlights/Progress

In the project several reference standards and work piece like standards, both simple (Fig 1) and complex (Fig 2) are used. The purpose is to evaluate use of calibrated CAD models. The simple shape has been manufactured and measured using tactile CMM. On the simple shape piece the larger cylinder (Fig 1) was planned and manufactured to have roundness error with a triangular shape. The upper cylinder was planned and manufactured to have roundness error with an elliptic shape.

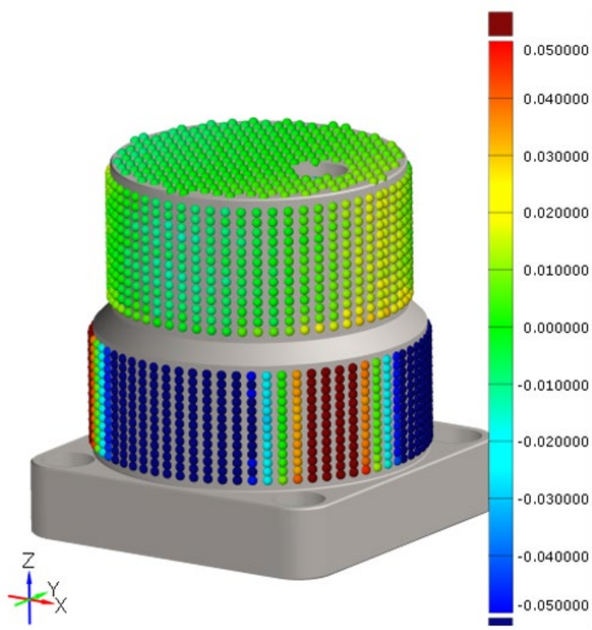

Figure 1. Work piece like standard used to demonstrate procedure to correct CAD model.

CMI, DFM and DTU design of wind blade artefact

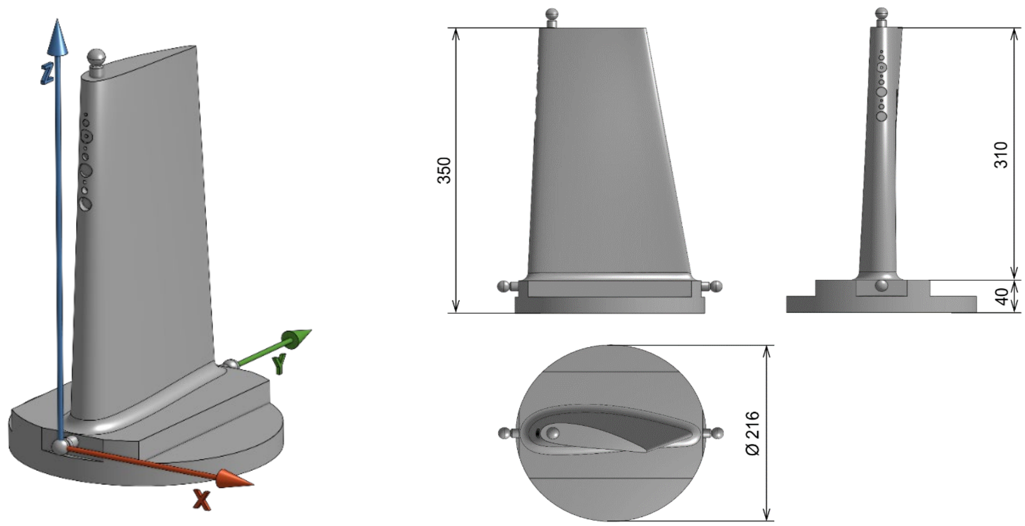

Figure 2. Artefact with freeform geometries, which represent the curvatures present on WES blades.

The wind blade artefact was designed and manufactured by CMI with DFM and DTU support. On the artefact leading edge have been placed an artificial erosion that will be verified using different measuring systems. The coordinate system is determined by the position of 3 precise ceramic spheres which are distributed around the freeform surface. Calibrated data from CMM tactile calibration will be compared with the data from optical 3D scanners and photogrammetry cameras placed on the drones. The developed calibrated CAD of wind blade artefact will allow complex verification of different optical systems.

The focus is on supporting interlaboratory CAD-based measurement evaluation, by using a reference calibrated (corrected) CAD model that better matches the actual shape of the measured object than the nominal reference geometry.

At PTB and VTT comparison tests between optical sensor and tactile sensor are also done, with focus on reproducibility, speed and accuracy.

Sensors for measurement of gears are tested at PTB. Figures 3-4 show a new fully motorized probe head at PTB with two rotation axes, axis A (± 105°) and axis B (± 180°). These axes can be indexed in 2.5° increments. It not only increases the flexibility of measurement, but also expands the measurement range. The optical probe attached to the probe head is a HP-O sensor from Hexagon. This probe has sub-micron resolution, and its measuring principle is based on frequency modulation interferometry.

The combination of the probe head and the HP-O sensor is currently used to measure the three external involute gears and the three internal involute gears on the 2 m diameter ring gear measurement standard at PTB. When using the optical probe, the measurement mode is scanning, which can significantly improve the measurement efficiency while ensuring the measurement accuracy. As reference data are the comparative measurements from several institutes and companies in 2015 and the PTB's recent measurement results using a traditional tactile probe.

In Figure 4, the HP-O sensor with a measuring direction of 90° is measuring an internal involute. In previous tests, it was found that large measuring angles (more than 20°) caused noticeable deviation and noise in the optical measurement result. By setting the two rotation axes of the rotary probe head, the measuring direction of the optical sensor can be set nearly perpendicular to the tooth flank, which can reduce the deviation and noise caused by the measuring angle.

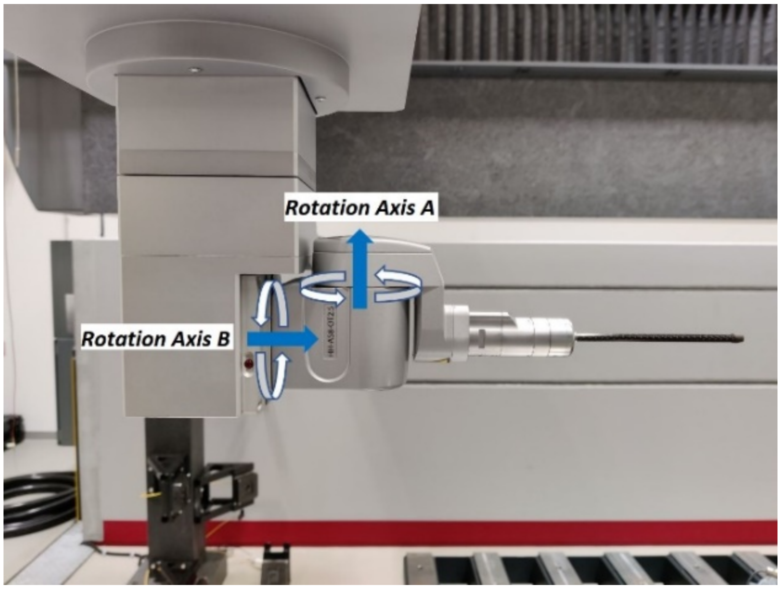

Figure 3. HP-O Sensor and probe head oriented in +X direction (view: +Y).

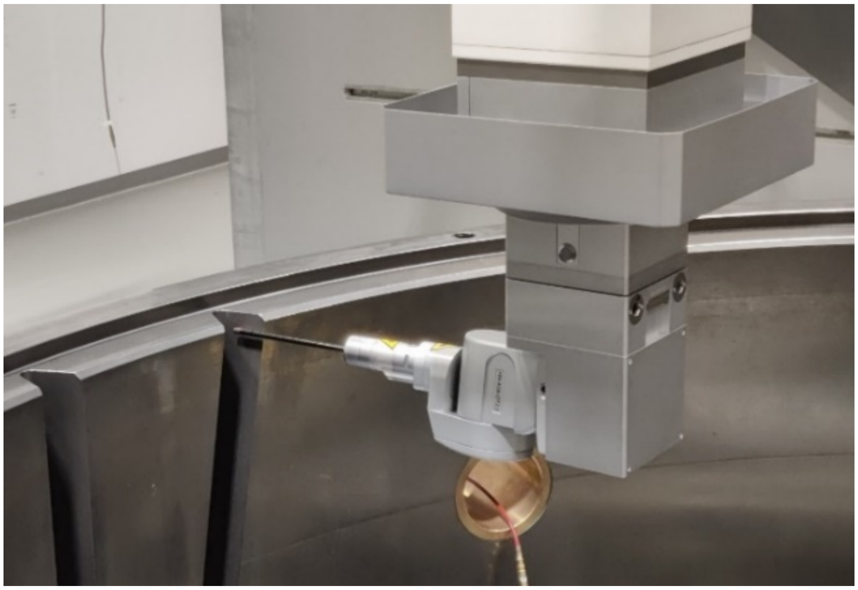

Figure 4. Measuring an internal gear.

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Different probes for measurement of run-out are tested by VTT and Aalto in cooperation with the unfunded partner ABB (Fig 5). In multi probe roundness measurement, the centre point movement of a workpiece is superimposed onto the probe signals. The eccentric clamping of the workpiece causes different influences on the measurement results, which need to be separated.

To test possibilities to use optical instruments for 3D scanning of wind turbine blades a freeform artefact is developed. The purpose is to evaluate the achievable measurement uncertainties.

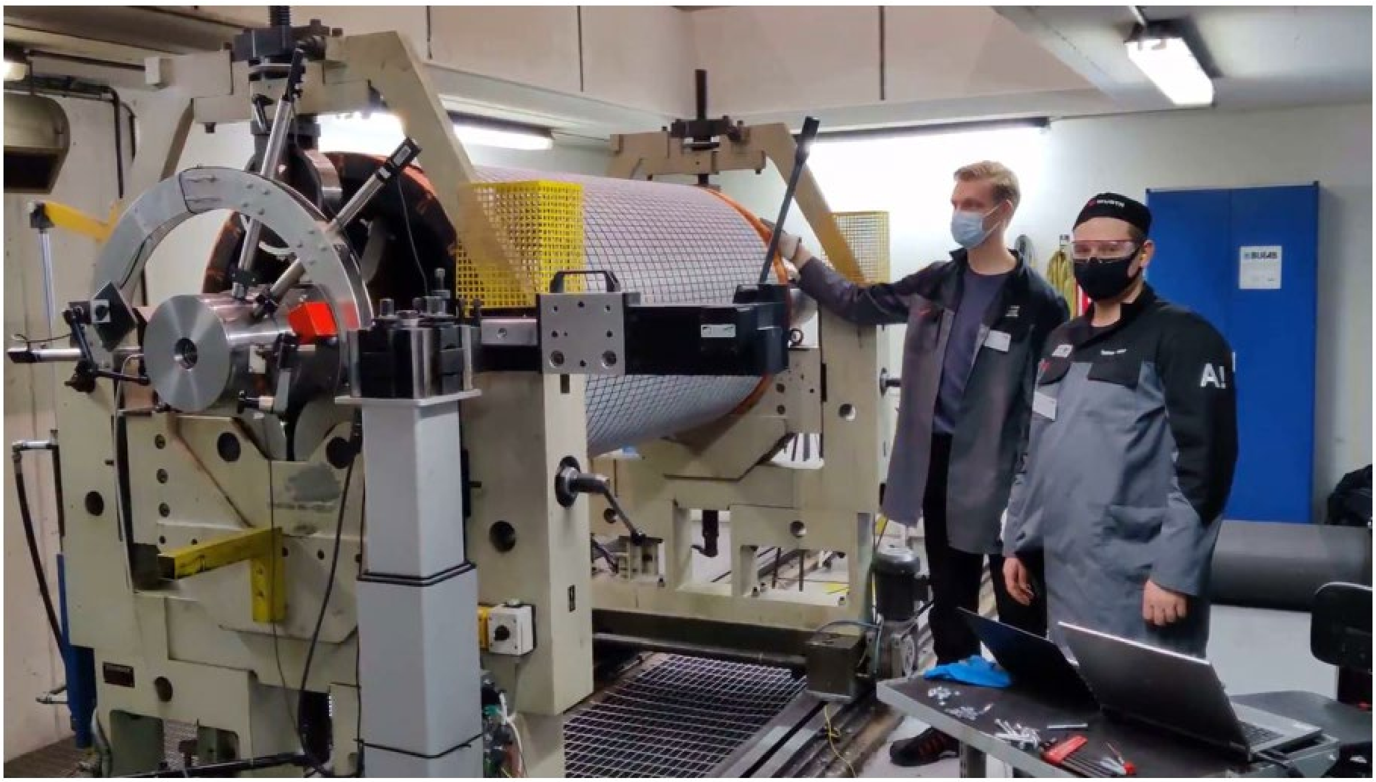

Figure 5. Testing of different probes for run-out measurements at Aalto University in cooperation with the unfunded project partner ABB.

NCL is investigating the use of portable laser scanners and soft moulded replicas to evaluate and characterise in service damage on gear surfaces. Damage such as micro pitting, macro pitting and scuffing can occur during normal operation, but the extent and depth of the damage is difficult to characterise by visual examination. Accurately characterising the damage allows informed maintenance planning and provides information for Digital Twin models and promises future design improvements. The project has investigated form removal methods and filtering methods to characterise damage on small demonstrator gears, validated by measurements on CMMs and GMMs. A number of candidate form removal, fitting and filtering methods have been investigated but the limits of application are still being investigated.

Full 3D gear surface measurement methods have been investigated using a GPS compatible holistic approach to gear tooth surface characterisation. PTB investigated two methods: applying an unconstrained fitting method and a constrained with nominal core gear geometry specification. The methods were tested using a small demonstrator master gear, as illustrated in Figure 6. The methods were introduced to the gear industry at the American Gear Manufacturers Association (AGMA) Fall Technical Meeting by PTB in November 21.

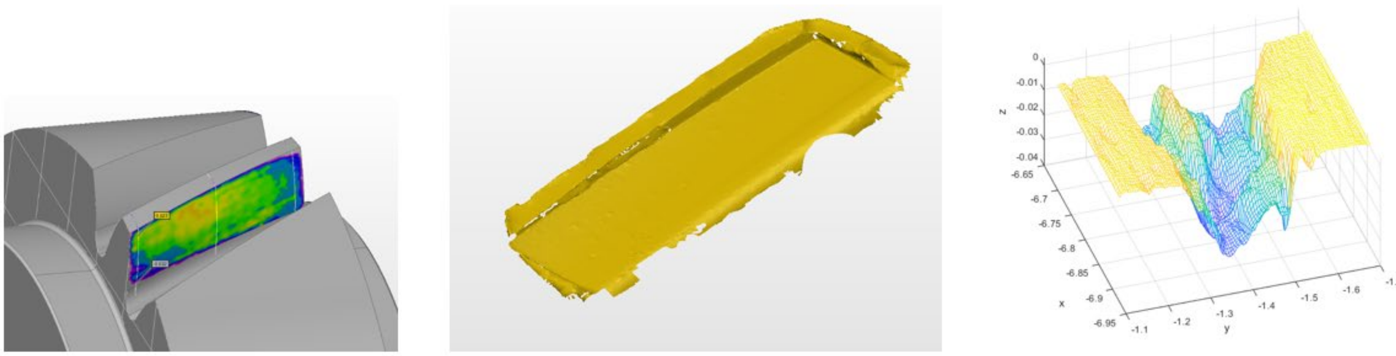

Figure 6. Characterising damage in example demonstrator gears. (L to R Hexagon Romer Arm laser scanner measurement results fitted to the nominal gear geometry, portable laser scanner measurement on a flexible replica surface, Alicona optical measurement evaluation on a soft replica).

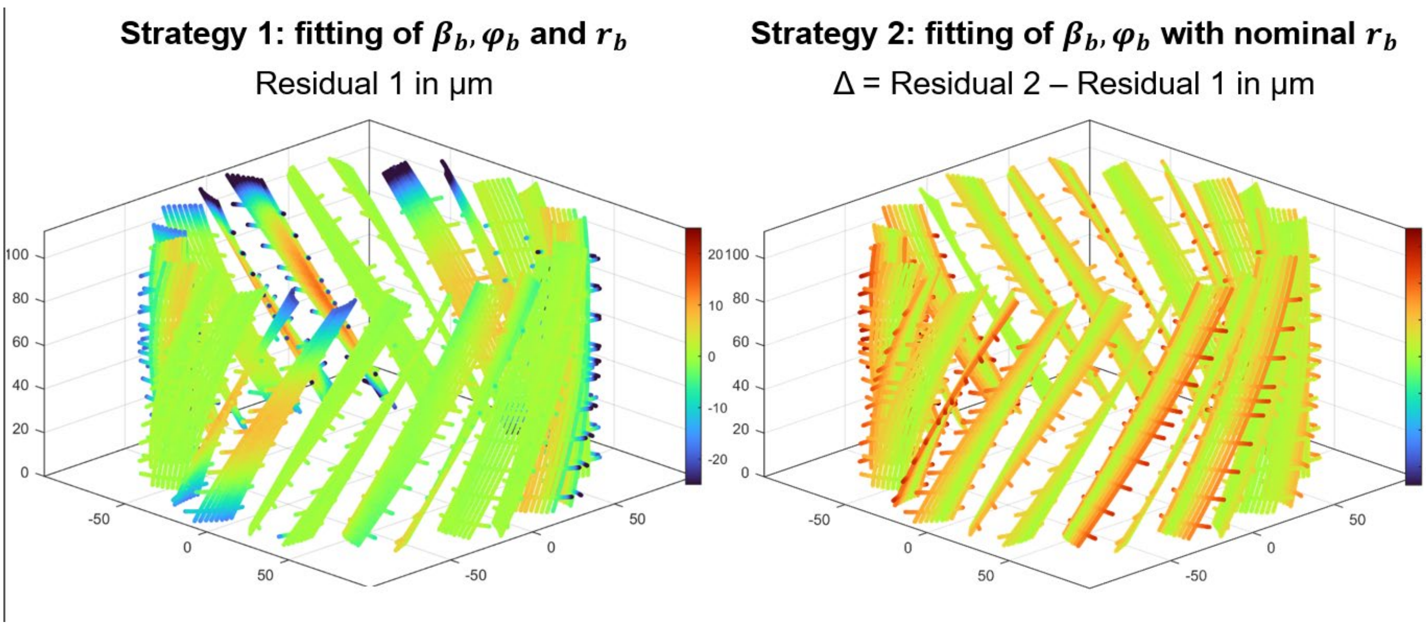

Figure 7. Residual gear surface evaluation from two strategies. (L resulting residuals from the unconstrained method and R, the difference between the residuals from the 2 methods)

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The 1st strategy is a paradigm change in classical gear evaluation methods. It is a pre-requisite to enable gears to be evaluated in accordance with Geometrical Product Specification (GPS) strategies. The new strategy provides significantly more information than the classical methods of measuring gears (Fig 7). One potential use of this is gear surface harmonic content evaluation which is being investigated by NCL. Characterising harmonic content on gear surfaces can be used to predict noise risk, improve contact stress modelling, and identify damage. Several methods are being investigated including classical DFT (Discrete Fourier Transform), Bayesian informed DFT and DWT (Discrete Wavelet Transform). An example of the application of a 2D DFT for the synthesised gear surface illustrated in Figure 8.

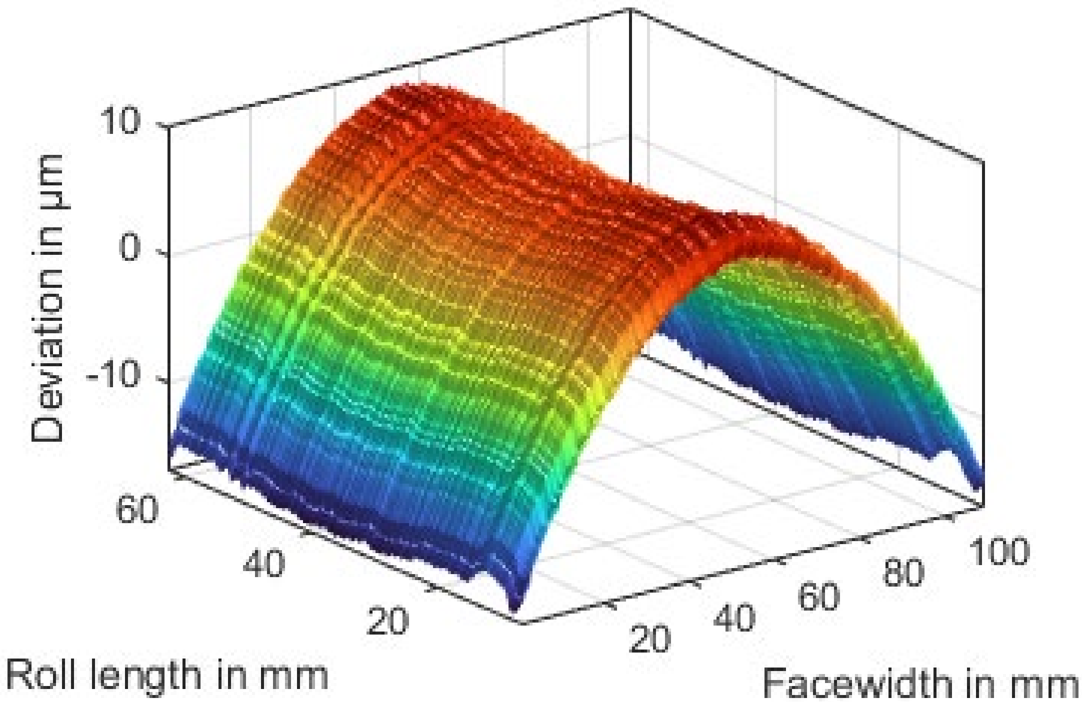

Figure 8. Synthesised 2D gear surface to evaluate the potential benefits from a 2D DFT.

The resulting 2D DFT shown in Figure 9 successfully extracts harmonic content which could excite noise or vibration in gears and provide a strategy to compare and evaluate machine tool harmonic characteristics. Furthermore, harmonic evaluation is being investigated as a method of compressing the gear surface measured data for transfer to CAD packages and Digital Twin models.

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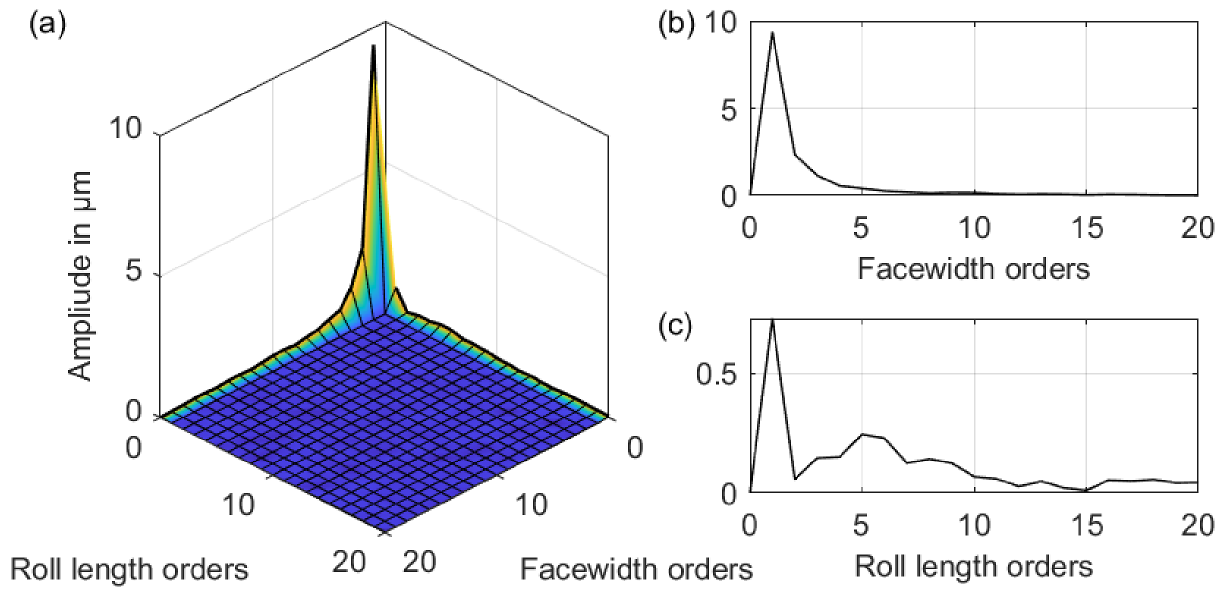


Figure 9. Example 2D DFT (L) with extracted harmonic content in the profile direction and facewidth or helix direction (R)

The application of rotary table self-calibrating methods developed by PTB for rotary tables on CMMs and is and illustrated in Figure 10 (L) showing a reduced three-rosette method that is quick to apply and evaluate. This method is being applied to by NCL to machine tools to investigate the feasibility of calibrating machine tool spindle accuracy for gear manufacture with unfunded partners NCMT on an Okuma machine tool (see Figure 10 (R) .

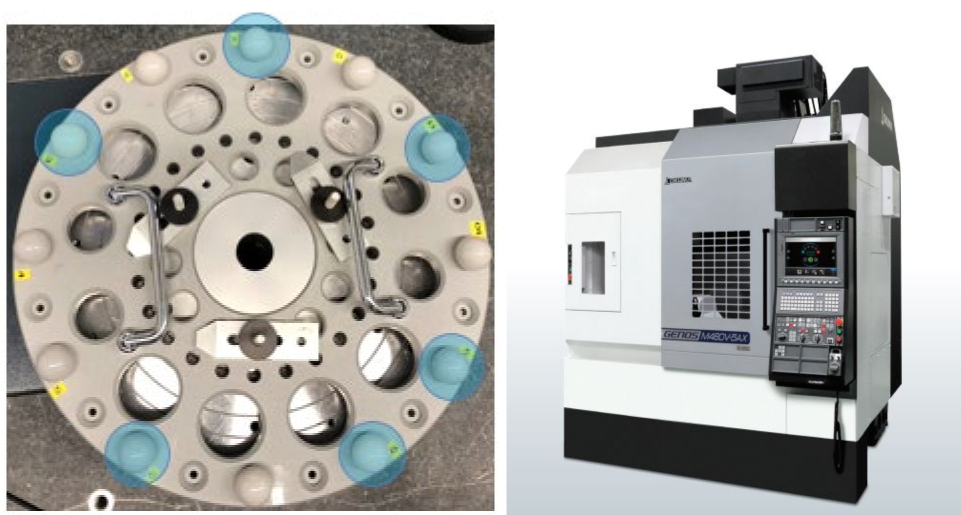


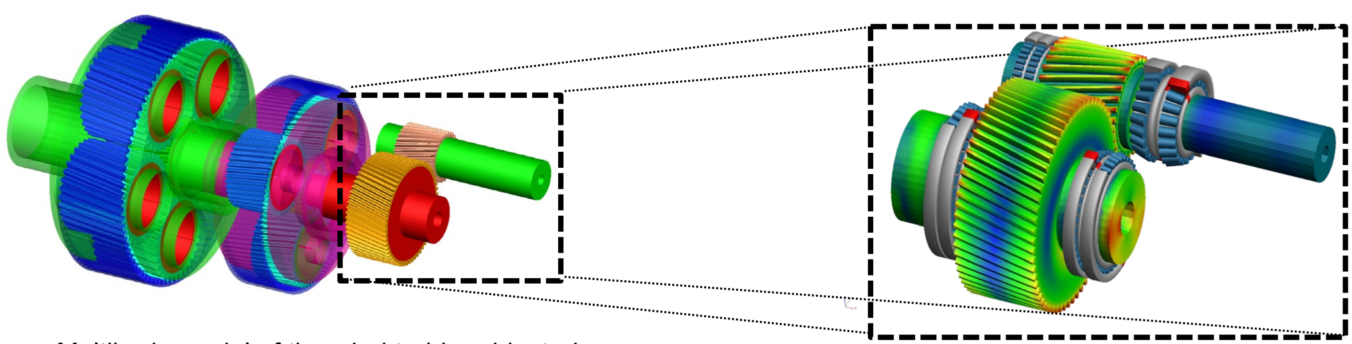
Figure 10. A conventional PTB ball plate with selected balls for the reduced method (Left) and a 5-axis machine tool from unfunded partners NCMT (Right)

AU is working on the digital twin (DT) of the WES to show the value of the generated measurements. The DT is intended to improve fatigue life estimation, maintenance prediction and overall reliability effects of the as built WES product. The DT utilizes detailed knowledge for specific components gained through their physical models. The strategy followed is a multi-resolution DT approach, which implements a high accuracy level at those components of special interest or more likely to fail. The baseline model is developed with multibody techniques using flexible bodies to represent the components of the drivetrain that are judged to have a significant effect on drivetrain degradation. The flexibility causes changes in contact stresses and dynamic loading that could significantly reduce drivetrain lifetime. For those parts where micro-geometry modifications are introduced, high-resolution models are used to accurately capture the impact of such deviations. These models are developed in Hexagon's Adams and Romax software. This enables the modification of the tooth profile by using real measurements.

Currently, we have developed a multibody model of a 10 MW drivetrain (Wang, Nejad et al. 2020) which will be employed as a baseline model (Fig 11, left). It introduces simplifications to account for gear contact and bearing elements. The third stage is known to be one of the most critical elements due to its high working speed. High-resolution models are already developed (Fig 11, right) that consider gear contact and bearings via FE as well as gear dynamics.

Medium-resolution multibody model of 10 MW wind turbine drivetrain

High-resolution flexible modelling of parallel stage



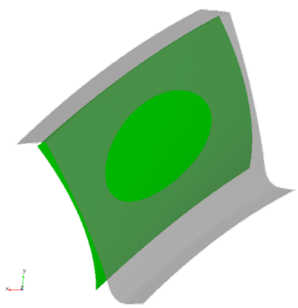
- Multibody model of the wind turbine drivetrain.
- Flexible bodies representing shafts, planet carrier and outer rings.
- Simplified contact interaction between gears by using a contact stiffness.
- Bearings simplified as bushing elements

- High-resolution modelling of the most critical parts.
- Contact interaction studying via FE.
- Gears considered as flexible bodies.
- Bearings introduced via FE.

Figure 11. Multi resolution models of WES drivetrain.

The use of high-resolution models enables an accurate description of the tooth profile, accounting for macro-modifications, standard micro-modifications and/or measured profiles (Fig 12, left). Moreover, contact stress between gears can be obtained by high-resolution modelling making it possible to analyse in detail the impact of profile deviations and dynamic loading (Fig 12, right).

Tooth profile modifications



- Macro-modifications (pitch deviation and runout)
- Standardized microprofile modifications (crowning, barreling,…)
- Measured microprofile

Simulated maximum contact stress under dynamic conditions

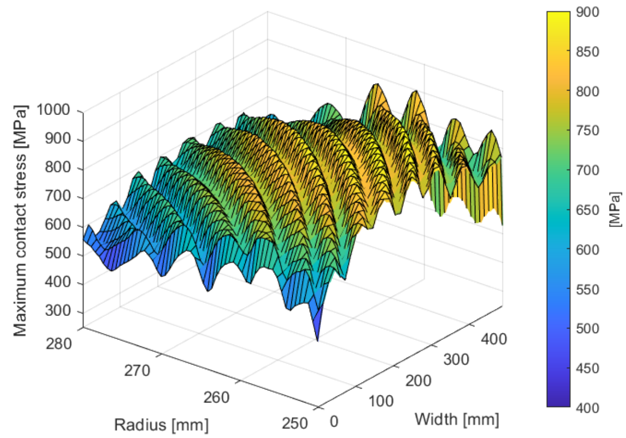


Figure 12. High resolution modeling of tooth profile and contact stress.

Impact on relevant standards

The project has been very active with participation at 15 national and international standardization committees. It was presented to ISO TC 60 Gears WG2 Gear Accuracy, at DIN NA 060-34-11 AA Zylinderräder - Terminologie und Toleranzen, at VDI/VDE FA 3.61 Verzahnungsmesstechnik and BSI Gears committee MCE/5.

Longer-term economic, social, and environmental impacts

The developed measurement procedures and uncertainty estimations will also be transferable to other production processes. Optical sensors, holistic evaluation strategies, the metrological use of DTs and in-line metrology are important subjects for a broad variety of engineering industries that will also benefit from the project's findings in the long term.

The deployment of wind energy in Europe is a remarkable industrial success. The outcome of this project will help to foster Europe's position among other countries regarding the growth of renewable energy systems.

This project will improve metrology for mechanical WES components and enhance industrial production processes. This will lead to better products and increase the availability and energy efficiency of wind power plants. Finally, it will help to accelerate the energy transition and thereby reduce environmental pollution. In addition, more effective, safer and quieter WES will raise the population's acceptance of this technology and thereby facilitate its further expansion.

Stakeholder Committee

The Stakeholder Committee will provide the consortium with information to help them steer the project and they will receive the project's results first hand. The aim of the Stakeholder Committee is to clarify the needs of the various interested parties, to feed these into the project and to ensure that the project remains focused on practical, applicable and essential research. The Stakeholder Committee has members from wind turbine manufacturers (Moventas and Vestas), metrology companies (Mitutoyo, Zeiss and Hexagon) and British Gear Association (BGA).

Some facts:

Project start date and duration:	September 2020, 36 months	
Coordinator: Martin Stein, PTB Tel: +49 531 592 5335 E-mail: martin.stein@ptb.de Project website: https://www.ptb.de/empir2020/met4wind/home/		
Internal Funded Partners: 1. PTB, Germany 2. CMI, Czech Republic 3. DFM, Denmark 4. INRIM, Italy 5. NCL, United Kingdom 6. VTT, Finland	External Funded Partners: 7. Aalto, Finland 8. AU, Denmark 9. DTU, Denmark	Unfunded Partners: 10. ABB FI, Finland 11. Hexagon, Germany 12. Moventas, Finland 13. NCMT, United Kingdom 14. SKF, Finland 15. Vestas, Denmark 16. Zeiss, Germany

List of publications

1. T. Tianen, R. Viitala, T.P. Holopainen, B. Hemming, Analysis of total rotor runout components with multi-probe roundness measurement method, Measurement, Vol. 179, 2021, 109422. https://doi.org/10.1016/j.measurement.2021.109422
2. M. Stein, F. Keller, A. Przyklenk, A Unified Theory for 3D Gear and Thread Metrology. Appl. Sci. 2021, 11, 7611. https://doi.org/10.3390/app11167611
3. A. Przyklenk, M. Stein, T. Reavie, R. Frazer, Holistic Evaluation of Involute Gears, AGMA 21FTM17 Technical Paper, ISBN: 978-1-64353-111-3

This list is also available here: https://www.ptb.de/empir2020/met4wind/information-communication/publications/

Met4Wind is coordinated by:

Physikalisch-Technische Bundesanstalt (PTB)

PTB
Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

Project partners:

INRiM Istituto Nazionale di Ricerca Metrologica

Newcastle University

Aarhus Universitet

DTU

NCMT

Czech Metrology Institute

VTT

ABB

SKF

Vestas

DFM Danish National Metrology Institute

Aalto University

Hexagon Manufacturing Intelligence

Moventas

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