Final Publishable JRP Summary for ENG56 DriveTrain Traceable measurement of drivetrain components for renewable energy systems

Overview

Renewable energy systems are a vital way of guaranteeing sustainable energy for the future, and wind turbines are regarded as one of the most promising technologies. However the reliability of wind turbines needs to be improved as they rarely reach the desired lifetime of 20 years without mechanical failure of the major drivetrain components. The drivetrain of a wind turbine is composed of the gearbox, the generator, and the necessary components that a turbine needs to produce electricity. Mechanical failure of any of these components can be expensive to repair and lead to downtimes of several days, or even weeks, resulting in significant cost in terms of lost energy production. These issues are likely to become worse as wind turbines become larger and offshore installations become more common, i.e. with the associated access and safety issues. The principal problem is that NMIs do not currently offer calibrated measuring standards for drivetrain components because they are so large, and even measurement processes for industrial large component measurements are insufficient. This project therefore developed measurement techniques for drivetrain components and traceable standards that were appropriate for large parts. These were then put into practice by manufacturers in order to have the potential to increase the reliability of drivetrain components.

Need for the project

The European Directive 2009/28/EC on renewable energy, implemented by EU member states in December 2010, set an ambitious target of reaching a 20 % share of energy from renewable sources by 2020. Wind energy systems (WES) are regarded as one of the most promising technologies for the generation of renewable energy to meet these targets, however their mechanical reliability needs to be improved.

Most failures in WES are due to electrical failures and are easy to repair with only a short interruption to service. However mechanical failures of the drivetrain components can also occur, and are expensive and time-consuming to fix, often resulting in days of lost power generation or a reduction in the life of the WES. WES are expected to increase in power, and therefore size, over the next few years and will increasingly be situated offshore, excacebating failure rates and repair costs.

The drivetrain of a wind turbine contains large gears, bearings, shafts and brakes. The shafts are up to 3 m in length and 1 m in diameter, large bearings are up to 3 m in diameter, internal and external involute gears up to 3 m in diameter, and brakes up to 1 m in diameter. Mechanical failure of a wind turbine drivetrain can be caused by dimensional inaccuracy, which can cause wear and localised heating. Surface condition, such as waviness or roughness, can also have a significant influence on the lifetime of highly stressed components because failures are often initiated at the surface. In addition, effects such as fabrication temperature and temperature gradients across a part or clamping can also be detrimental in such large components.

Comparison with the automotive industry shows that large scale drivetrain components for WES are a long way from the high performance and low failure rates seen in the automotive industry. In automotive engine parts, traceable measurements are the backbone of the fabrication processes and quality control, and automotive gears are optimised in terms of weight, surface quality and dimensional stability. In contrast WES fabrication does not currently have such rigorous, traceable measurements and manufacturing standards. Prior to this project, there were no calibrated measuring standards for large drivetrain components, and most NMIs had little or no experience in measuring large-size components. There were also no qualified measurement techniques for surface quality.

EMRP
European Metrology Research Programme
Programme of EURAMET

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Scientific and technical objectives

This project aimed to develop measurement standards and procedures to improve the accuracy and reduce the uncertainty of quantitative measurements for highly precise drivetrain components. Reliable measurement with low uncertainty is the first step towards better quality control of the complete manufacturing process, and towards more reliable components. The project had the following objectives:

1. To provide metrology solutions for measuring and characterising size, form, waviness and surface roughness parameters in large drivetrain components, establishing functional characterisation parameters in accordance with established written standards.
2. To research and develop novel measurement standards and calibration procedures for establishing traceability and estimating measurement uncertainty of drivetrain components
3. To establish and quantify the key additional sources of uncertainty that influence industrial measurement capability
4. To develop a virtual measuring process which includes all the significant uncertainty contributions from the workpiece, environment, measuring strategy, and measuring instrument
5. To test the developed measurement standards in industry and critically analyse the performance compared to traditional standards, such as gauge blocks, step gauges, etc.

Results

Metrology strategies for measuring and characterising large drivetrain components

Six good practice guides for shafts, gears, bearings, and gear measurements were developed and trialled in real industrial applications under harsh environmental conditions. The good practice guides deal with measuring length, surface form (including waviness) and roughness of large drivetrain components. Where guidelines already existed for accredited laboratories, they have been interpreted for industrial use. Recommendations on which properties and parameters to measure for different parts were also made for:

- involute profiles (the profile of the teeth), including superfinished surfaces
- braking systems
- gears, and
- involute helical gears

The good practice guides developed in this objective have established the necessary metrological procedures and recommendations for measuring large drivetrain components, taking into account the effect of temperature, environmental conditions, the effects of gravity and clamping effects. The good practice guides also established functional characterisation parameters in accordance with established written standards e.g. ISO 10825, ISO 5436, ISO 13565, ISO 16610, ISO 12180, ISO 12181, ISO 12780, ISO 14405 (see guides for details).

Novel measurement standards and calibration procedures for drivetrain components

This objective established traceability and uncertainty estimations for large drivetrain components, using the procedures from the first objective. Nine standard artefacts for large gears, bearings, and shafts were designed and manufactured. Novel measurement equipment procedures were then developed by the project to measure and calibrate these standard artefacts as well as other large industrial parts/drivetrain components. These procedures and standard artefacts have been used by industrial manufacturers so that they can calibrate their drivetrain components.

Measurement uncertainty under typical conditions in industry

The project undertook end-user surveys of typical fabrication and processing conditions for large gear and large bearing metrology, as well as typical supports and clamping fixtures for large rings or bearings. The surveys were carried out with four industrial stakeholders who are manufacturers of drivetrain components. Thermalisation experiments, where large parts reach thermal equilibrium, were carried out using a climate chamber. The effect of self-weight deformation of large rings was also investigated, and the results from both have been published in a good practice guide for industrial users on the thermalisation times of large gear and large ring measurement standards. Lastly, the measurement uncertainty due to elastic deformation of components was examined, particularly for the wind power generator tower. Based on the findings of the surveys, and the above experiments in industrial conditions the project has been able to establish and quantify the key additional sources of uncertainty that influence industrial measurement capability. This greater knowledge of the measurement uncertainties allows much better quality control in the production of drivetrain components.

Virtual measuring process for traceably measuring large drivetrain components

The project developed computer-aided design (CAD) modules and numerical models, and used these to simulate the significant factors that introduce errors in the measurements of large components. These virtual investigations considered surface characteristics, temperature variations and deformations caused by gravity and clamping. Based on their results it is now possible to minimise these errors in the measurements of large components by using the recommendations resulting from the numerical models/calculations.

Furthermore, recommendations for the selection of scanning parameters for coordinate measurement machines (CMM) from numerical simulations and practical experiments. These recommendations and those from the virtual investigations above are now available for end users as a good practice guide on the minimisation of significant measurement uncertainty contributors such as gravity and clamping. The direct application of these recommendations within finite element analysis packages and design software developed by the project, can be used to predict both failure modes and the functional performance of drivetrain components.

Validation of measurement strategies and determination of achievable measurement uncertainty in industrial environment

The project's six good practice guides were found to be easily to use and applicable in practice in an industrial environment. Using the guides the project was able to validate the measurement strategies developed in the previous objectives in an industrial environment. The knowledge gained was also used to analyse the performance of existing fabrication and handling methods including traditional standards, such as gauge blocks and step gauges. From the results, it was possible to establish uncertainties, which were typically within 2 µm to 10 µm.

Actual and potential impact

Dissemination of results

The results from the project were presented internationally at more than 20 conferences and workshops, including The European Society for Precision Engineering and Nanotechnology (EUSPEN) 2016, and 2017, The American Society for Precision Engineering (ASPE) 2014, and The International Academy for Production Engineering CIRP 2015 and 2016. In total 18 presentations were given and 6 posters presented. 15 articles were published in scientific peer-reviewed journals, as theses and in trade magazines. Additionally, the project was presented at the trade fairs Control 2017 in Stuttgart, Hannover Messe 2017, and WindEnergy 2016 in Hamburg.

Further to this, 17 training courses on Surface characterisation and Gear Measurement were given by partners NPL and DTU to support knowledge exchange with industry and to broaden the application areas for the results of the research.

The following six good practice guides for optimised measurement of large-dimensional measurements were produced by the project:

1. Good practice guide on the thermalisation times of large gear and large ring measurement standards
2. Good practice guidance for minimisation of significant measurement uncertainty contributors such as gravity and clamping
3. Good practice guide for surface parameter detection on gears
4. Good practice guide for surface parameter measurement strategies for form and diameter measurements for large bearings
5. Good practice guide for surface parameter measurement strategies for waviness and roughness measurements for large bearings

6. Good practice guide for surface parameter measurement strategies for form and diameter measurements for large shafts

These good practice guides can be accessed on the project's website: http://www.ptb.de/emrp/2757.html.

Impact on standards

The existing standards for dimensional measurements often have no upper limit on the size of the component that they apply to. Therefore, relevant standard committees such as ISO/TC 213 Dimensional and geometrical product specifications and verification and ISO/TC 60 Gears were regularly updated by the project on its results so that this factor could be included for future updates.

Actual impact

The project identified, modelled, quantified and validated in industrial practice, the key sources for uncertainty for dimensional metrology on large drivetrain components. The project's results are already being used by:

- Kankaanpää Works, a Finnish machine workshop, is using the measurement methods and evaluation strategies for large diameters and they are working with their subcontractors to follow similar principles.
- The Laboratory for Machine Tools and Production Engineering from the University Aachen, will use the measurement standards/aretfacts from the project for further research work.
- CMI and IMRIM have both established a gear calibration service.
- PTB is using the project's calibrated large ring gear measurement standard.

Potential impact

The improved metrology developed by this project means that the manufacturing of large drivetrain components can be improved, with better quality control of the complete manufacturing process, and more reliable components. From experience in other industrial manufacturing situations, this will help to extend the lifetime of WES generator components and reduce their failure rate.

The project's Good Practice Guides and recommendations from the numerical simulations can also be applied in other sectors manufacturing large parts, with similar measuring tasks, such as naval, railway or aircraft industries.

Metrology-driven fabrication produces the functional parts in a single process, or within very few steps, and does not need optimisation cycles. This better quality control has the potential to reduce the production costs of large drivetrain components by 25 %.This would then lead to WES becoming cheaper and therefore support increased installation of WES with the same investment level. The mandatory introduction of traceable measurements into the manufacturing process of WES components is required by an increasing number of standards and will lead to increased turnover for measurement equipment and calibration suppliers. As a result, this project will support the economic efficiency of the production of renewable energy and hence support the EU H2020 goal of reducing CO_2 emissions by 40 % by 2030 for power generation.

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