Project title	Wind turbine drive train system dynamics
Project number	TG3-1
Organisation	Chalmers University of Technology, Applied Mechanics
Project leader	Viktor Berbyuk
Other participants	Saeed Asadi (PhD student: March 2013-March 2016), Håkan Johansson, Jan Möller
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Participating companies	SKF

Project description

The dynamics of wind turbines is complex and a critical area of study for the wind industry. The multidisciplinary nature of wind turbine design adds to the complexity of this task, as the subsystems of a wind turbine need to be tuned with respect to a common objective to achieve a cost effective and optimum structural performance [1]. The project is a continuation of the since March 2013 running Ph.D. project having as a main focus drive train system dynamics of wind turbines. The drive train system is here considered as the electro-mechanical subsystem comprising shafts, bearings, gearbox, shaft couplings, mounts, generator, and other functional components of a wind turbine that transfers mechanical power from the rotor hub to the electric power generator, and thereby plays an important role in a wind turbine dynamics [1]. The project includes both theoretical and experimental study of drive train system dynamics. It focusses on the high-speed shaft subsystem of indirect drive wind turbines and interaction between functional components and system dynamic response, faults modelling and detectability of defects in bearings in wind turbine drive trains.

Results

The mathematical and computational models of high speed shaft subsystem of wind turbine drive train have been developed by using Lagrangian formalism [2, 3, 5, 7]. The test rig of high speed shaft drive train was built, instrumented with SKF WindCon 3.0 condition monitoring system and used for experimentally study system vibration dynamics and load distribution. More details about the developed test rig are available in [3, 5, 6, 7]. By using the obtained measurement data, the developed mathematical and computational models have gone through model validation process by qualitative comparison of simulation and experimental data. Then the system kinematic and dynamic responses are studied for different operational scenarios and system structural parameters (ratio of shaft bending stiffness and stiffness of mounting structures, unevenly inertia load distribution, others), [3].

The dynamics of torsional vibrations and transient events which can reduce fatigue life of functional components of a wind turbine drive train high speed subsystem [4] was studied both by modelling and experiments. The system dynamic response is studied for different operational scenarios and structural parameters (transient-steady state-shut down cycle with and without eccentric mass, others). A simplistic motor model with slip and torque ripples is used within the system modelling. This gives an insight in how faults sources can contribute to the system dynamics of drive trains, [2]. The results also indicate that the current drive train system modelling could be decomposed into two main simpler subsystems focusing on torsional and bending drive train flexibilities separately.

Based on Multiplicative Dimensional Reduction Method, the global sensitivity analysis of high speed shaft drive train of wind turbine with respect to input structural parameters has been considered as one of the key stages of drive train system design. The variance based global sensitivity indices are introduced and the Gaussian quadrature integrals are employed to evaluate the contribution of input structural parameters correlated to the objective functions. For each operational scenario, the most effective parameters have been recognized for high speed shaft drive train. The primary and total sensitivities of the objective functions were examined with respect to each input parameter.

A reliable and computationally efficient algorithm has been developed for the global sensitivity analysis, which gives a beneficial insight into solving different optimization and design problems of wind turbines. It is shown that global sensitivity analysis results obtained can reduce the costs associated with a wind turbine design by significantly narrowing down the number of the design parameters to be used for optimization problems of a wind turbine drive train components, [7, 8].

Dynamic modelling and vibration simulation are important for fault mechanism studies to provide proofs for defect detection and fault diagnose. In this regard, it has been demonstrated that the proposed models of high speed shaft subsystem of a drive train could be used within global sensitivity analysis in order to investigate the detectability of faults in different components, [7]. By introducing defects in drive train functional components and investigating sensitivity indices, detectability of faults by global sensitivity analysis was proved [7, 8]. The results show that the proposed methodology is capable of detecting damage in the functional components such as bearings in early stage before a complete failure. The application of this methodology within the detection, prediction, and prevention framework has a potential to reduce the maintenance cost for critical components. The results can also provide a better understanding and useful hints in wind turbine drive train system dynamics with respect to different structural parameters, ultimately designing more efficient drive trains.

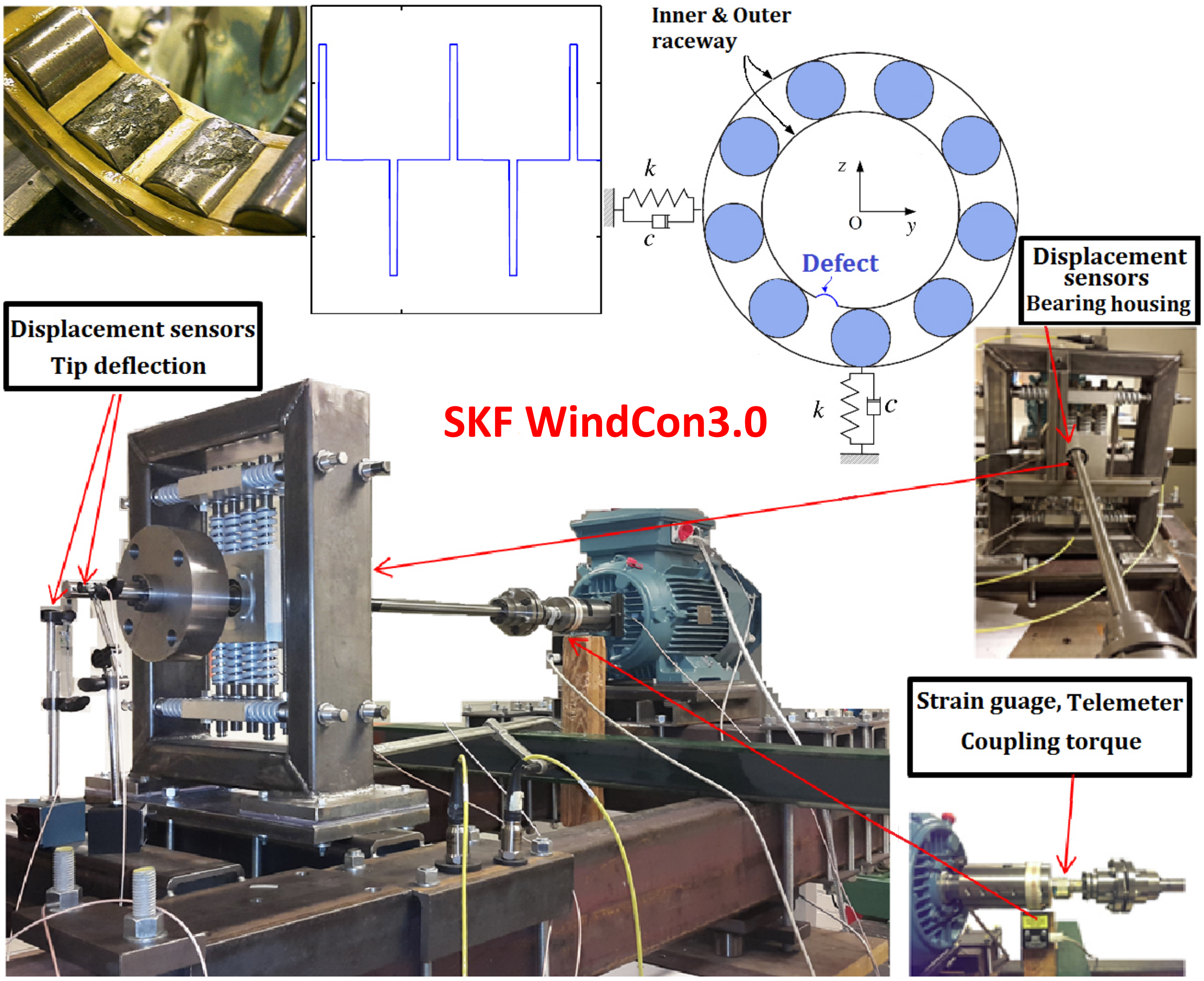

Fig. 1 The test rig of high speed subsystem of a drive train of a wind turbine

Publications

1. **Struggl, S., Berbyuk, V. and H. Johansson,** (2015), "Review on wind turbines with focus on drive train system dynamics". *Wind Energy*, Vol. 18, 4, p. 567-590, http://dx.doi.org/10.1002/we.1721
2. **Asadi, S., Berbyuk, V., and H. Johansson,** (2015), "Structural dynamics of a wind turbine drive train high speed subsystem: Mathematical modeling and validation", *In Proc. of the International Conference on Engineering Vibration,* Ljubljana, 7 - 10 September ; [editors Miha Boltežar, Janko Slavič, Marian Wiercigroch]. - EBook. - Ljubljana: Faculty for Mechanical Engineering, 2015 p. 553-562.
3. **Asadi, S., Berbyuk, V., and H. Johansson,** (2015), "Vibration dynamics of a wind turbine drive train high speed subsystem: Modeling and validation", *Proceedings of the ASME 2015 International Design Engineering Technical Conferences and Computers & Information in Engineering Conference IDETC/CIE***,** August 2-5, 2015, Boston, Massachusetts, USA, paper DETC2015-46016, http://dx.doi.org/10.1115/DETC2015-46016
4. **Johansson, H., Berbyuk, V.,** (2014), "Statistical analysis of fatigue loads in a direct drive wind turbine", Online proceedings of the European Wind Energy Association (EWEA) Annual Event 2014, http://publications.lib.chalmers.se/records/fulltext/196101/local_196101.pdf
5. **Asadi, S., Berbyuk, V., Johansson, H.,** (2014), *Simulation and analysis of dynamics of a wind turbine drive train high-speed shaft subsystem test rig, In Proc.* 27th Nordic Seminar on Computational Mechanics,NSCM-27, A. Eriksson, A. Kulachenko, M. Mihaescu and G. Tibert (Eds.), KTH, Stockholm, 2014.
6. **Squires, J. C., (2014),** *Measurement System Design and Experimental Study of Drive Train Test Rig.* M.Sc. thesis 2014:36, ISSN 1652-8557, Chalmers University of Technology, Göteborg, Sweden, 2014.
7. **Asadi. S.,** (2016), *Drive Train System Dynamics Analysis*: *Application to Wind Turbines.* Thesis for the degree of Licentiate of Engineering, 2016:01, ISSN 1652-8565, Department of Applied Mechanics, Chalmers University of Technology, Göteborg, Sweden.
8. **Asadi S., Berbyuk V., Johansson H.,** (2016), Global Sensitivity Analysis of High Speed Subsystem of a Wind Turbine Drive Train, Submitted for international publication.

External activities

During the project work national and international collaborations have been performed, namely with SKF, Scandinavian Wind AB, NREL, Colorado, USA on Gearbox Reliability Collaborative project, University of Mons, Belgium, and with University of Aberdeen, UK.