RELIABILITY OF MACHINE ELEMENTS IN WIND TURBINES

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Abstract. *Worldwide electrical energy production generated by wind turbines grows at a rate of 30 percent. This doubles the total production every three years. At the same time the power of individual stations goes up by 20 percent annually. Whereas today the towers, rotors and drive trains have to handle 5 MW, in about six to eight years they might produce up to fifteen MW. As a consequence, enormous pressure is put on the wind turbine manufacturers, the component suppliers and the operators. And because prototype and field testing is limited by its expense, the design of new turbines demands thorough analysis and simulation. Looking at the critical components of a wind turbine this paper describes advanced design tools which help to anticipate failures, but also assists in optimizing reliability and service life. Development of the software tools has been supported by research activities in many universities.*

Keywords: reliability, turbines, design

1. Background

The design of wind energy generators as a multidisciplinary approach has put a lot of new questions to mechanical engineers. Especially high failure rates of gear boxes have been a great challenge to industry. Today it is a fact, that never before experienced wind load characteristics and their dynamic influence on the system structure led to these breakdowns. But then, life goals weren't met, and insurance fees payable by operators and manufacturers went up dramatically. Therefore individual companies and associations together with research institutes set up projects to identify and solve the unforeseen problems [1,2,3]. Certification bodies started to refine rules and regulations, and even insurance companies began to look closer at wind power stations, their design and operating standards. Centered on the drive train, the behavior of machine elements like bearings, gear, shafts and clutches was heavily tested and analyzed. One of the universities, where gearbox and drive train design played a major role already for decades, is the Technical University in Dresden. Together with researchers from Institute of machine construction a spinoff company was set up, where the focus of development was aimed at simulation tools for gear and drives. Based on the results of long-time scientific research, the software projects at the new company DriveConcepts link advanced technical content to the proven and recognized simulation technology of MDESIGN.

2. Simulation of Machine Elements in Wind Turbines

The calculation and simulation tools described in this paper address most of machine and connecting elements used in wind turbines. The emphasis of the calculations is on prediction of service life and safety against failure. Multi-body dynamic analysis provides the loads acting on the structure and individual components. Software simulating flow conditions, civil engineering and electrical and control equipment, are not considered.

Fig. 1: MDESIGN calculation subjects

2.1 General Machine Element Calculations

Over many decades engineering design practice and standardization have led to an enormous amount of technical knowledge. Formulas, tables, diagrams und text have been put down on several hundred thousand pages, mostly unstructured and untraceable. In MDESIGN, a digital engineering handbook, a substantial part of this content was converted into design and simulation tools for mechanical engineering. More than hundred programs help to dimension mechanical components with respect to safety and reliability (Fig.1). Results you can also achieve with MDESIGN are material consumption, energy efficiency and total cost of ownership.

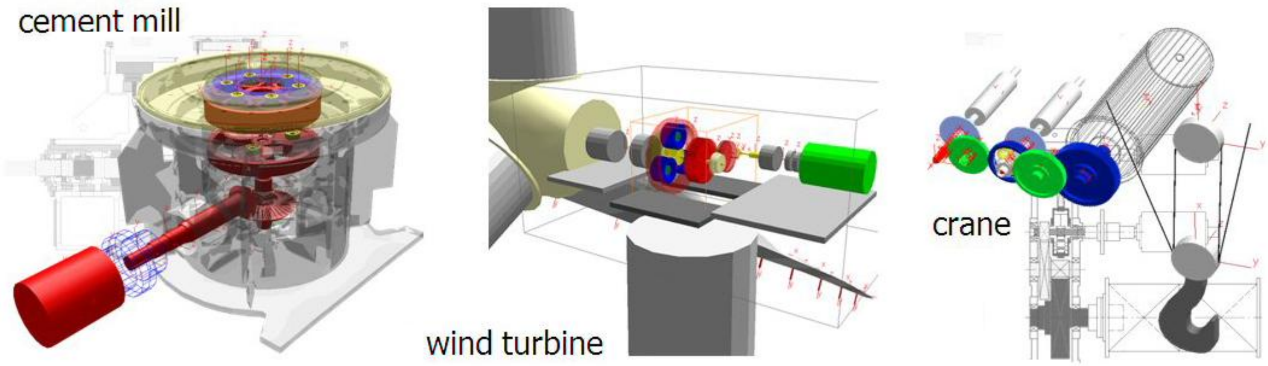

Fig. 2: Various Drive Trains with Alternating Loads

2.2 Simulation of Drive Trains in Wind Turbines

Analysis of machine elements embedded into an oscillating system (Fig.2) like a wind tower requires detailed knowledge of the applied loads. Furthermore, exact dimensions, material characteristics and boundary conditions must be known, in order to analyze the dynamic behaviour of the tower and its components (Fig.3). Up to now there is no general model available, which determines the loads and displacements at each point of interest. Therefore general simulation tools like Adams and Simpack are being used to calculate effective loads and frequencies across the structure. Fed with empirically detected wind profiles, today computerized simulations are able to generate very precise results. When looking at given configurations, they almost coincide with measured data. Simulations, we carry out at DriveConcepts, give the information we require as input for the design and verification of the drive train and the individual elements.

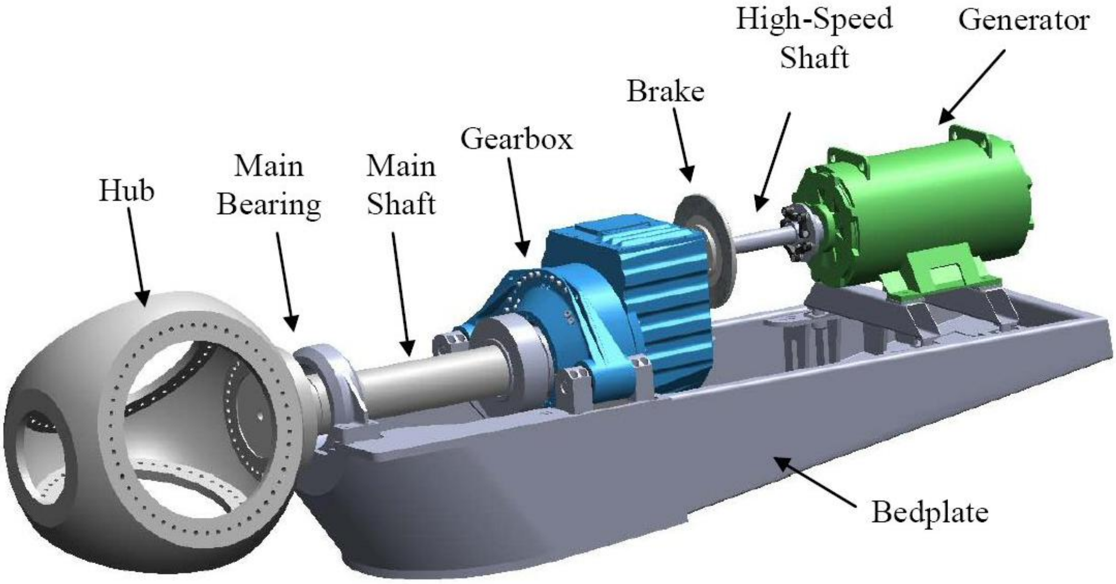

Fig. 3: Drive Train of a Wind Turbine

2.3 Gearbox Design

Since energy and material efficiency is in the focus of government and administration, research efforts have been stepped up by far to find new solutions for drives and drive components. Information technology has also opened new paths to more efficient design tools. And because of high growth rates many companies also have boosted their efforts to get a stake of the market. However, entrance barriers are high as the demanded service of the main components is around twenty years. But although gearboxes and bearings have been designed for centuries, it turns out that there is still a lot of potential left for improvements.

With MDESIGN gearbox the development and design of gear based drives will soon get new momentum. Mechanical designers for a long time preferred numerical simulation, neglecting profound and precise research work, analyzing the behavior of machine elements and linking the empirical knowledge to geometry and basic mechanics.

MDESIGN technology now links bearing, shaft and gear analysis to one central database and generates a holistic model of the gear (Fig.4)[4]. Relations between components are of geometric as well as of technical nature and the optimization procedure lets you calculate and compare thousands of option within minutes. An optimization project, done with five gearboxes from four different manufacturers, going for the optimum weight, led to 18 percent savings in material consumption, bringing the price down by almost the same size. Reflecting these savings in the wind industry, tower structures could become significantly lighter.

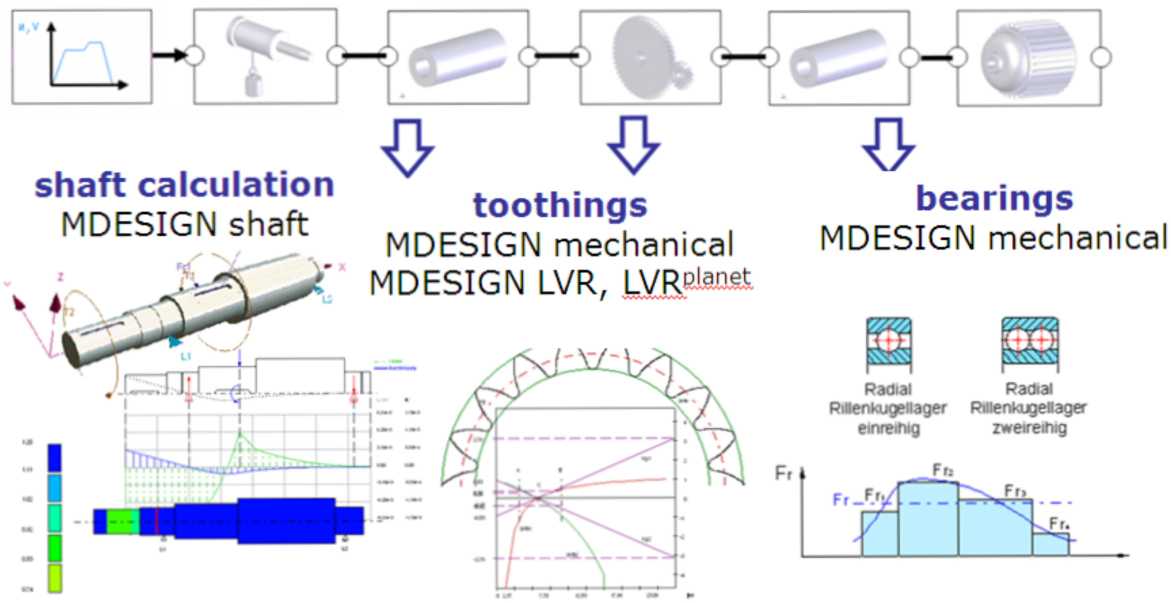

Fig. 4: Integrated Drive Train Development with MDESIGN Platform

2.4 Gearbox Optimization

Drive train design in wind turbines is one of the biggest challenges mechanical design has faced so far. Boundary conditions, displacements and size of the projects are extraordinary. Notwithstanding operators and systems manufacturers urge industry to supply increasingly powerful stations, although many of the problems of the present generation have not been solved.

Main reason for premature mechanical failures of wind power generators is the fragile structure exposed to highly dynamic wind loads as it has to carry massive metal components, blades, bearings, housings, shaft and gears. Such a structure may cause very destructive oscillations. In any case, tower and blade movements result in large deflections of the elastic components of the wind tower. Design theory of today only just starts to take care of these displacements, which lead to raised stress and strain [5,6]. One important area of concern is the contact stress in between gear pairs. As design and dimensioning rules for gear have been made for load cases without noticeable deformations, real shaft and gearbox displacements are not being considered. But in reality shafts bend and force the gear flanks to misalign and to uneven pressure distribution (see Fig.5). Conditions as we find them in wind turbine gearboxes are represented by simulation results of MDESIGN LVR as shown in fig.6 [7].

MDESIGN LVR, developed jointly between DriveConcepts, TU Dresden and TEDATA analyses stress parameters for spur and for planetary gear and helps to optimize the gear surface with the aim to get a low and even contact stress along the width of the tooth flanks. Because of the complicated geometry of the planet carrier the analytical calculation model in MDESIGN LVR planet is complemented by finite element analysis. Parametric models of mostly used carrier shapes calculate the deformations of the planet carrier, caused by different forces. These are required for an exact analysis of the tooth stresses [8,9].

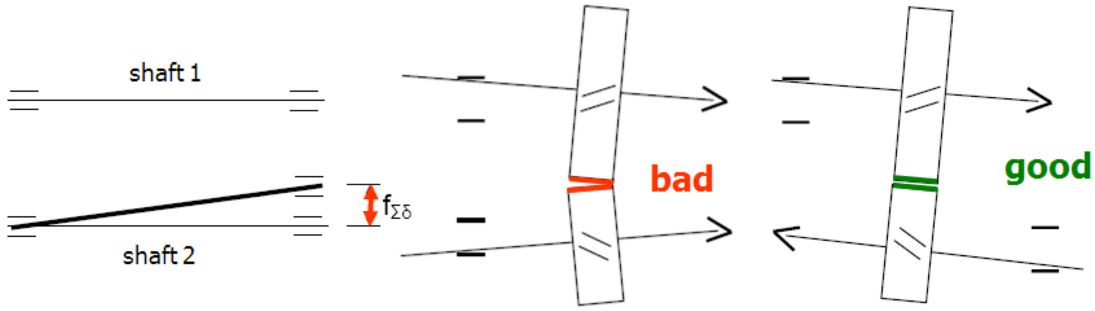

Fig. 5: Gear Position as Result of tolerances, deviation of bore hole position and bearing clearance

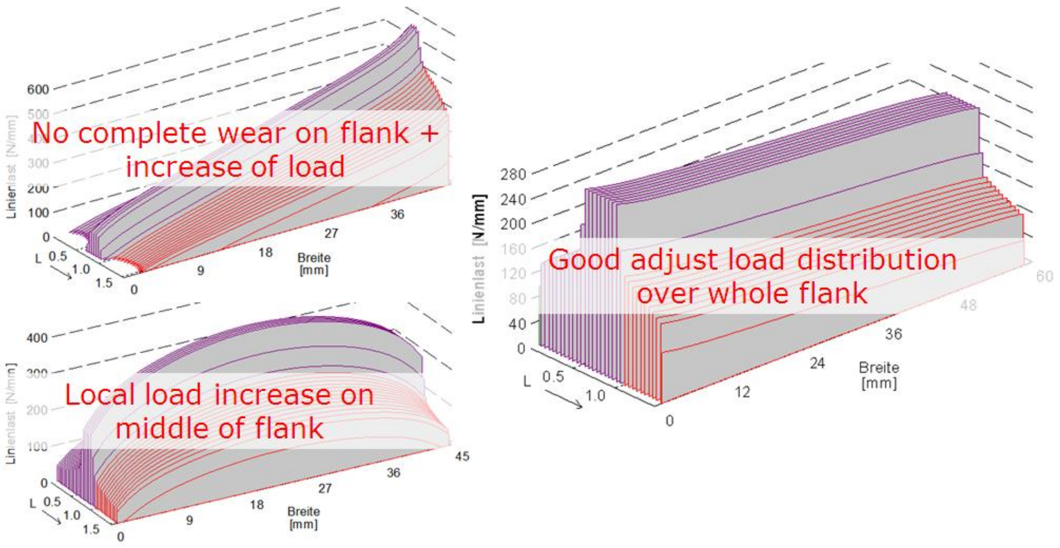

Fig. 6: MDESIGN LVR - Load Distribution at a Tooth Flank

3. Bolted Joints in Flanges and Clutches

A wind turbine assembles many individual components to a large and complex system. They all must be connected, and these connections experience the same loads as the structural and mechanical elements. Most of the connections have flange-like shapes and are mounted along the tower, at the blades und along the drive train (see Fig.7). Some of them act as fixed clutches. Dimensioning these bolted joints requires knowledge of the wind loads as well as of the static loads of the structure. The calculation procedure is based on the global acting forces. From here a program called MDESIGN ParaFEM determines the loads, acting on the individual screw. MDESIGN ParaFEM ist a library, which contains among others a series of parameterized finite element models for bolted flanges. MDESIGN ParaFEM takes into account, that the oscillating bending and rotating of the wind tower changes the load along the circumference of the flange. Therefore an individual screw gets a time-series of loads, due to the general wind load case.

Results of the verifying calculation are, the maximum assembly preload, the assembly stress and the permissible assembly preload, the working load, the alternating stress at dynamic working load the surface pressure in the assembled state and in the working state, the minimum length of engagement at single-bolted joints, shearing stress und the safety margin against slipping at a transverse load, the tightening torque.

Fig. 7: Bolted Joints at a Wind Turbine

References:

[1].Schulze, T.: *Ganzheitliche dynamische Antriebsstrangbetrachtung von Windenergieanlagen*, 264. S., Göttingen 2008

[2].Oyague, F.: *Gearbox Modeling and Load Simulation of a Baseline 750-kW Wind Turbine Using State-of-the-Art Simulation Codes*, National Renewable Energy Laboratory1617 , NREL/TP-500-41160, February 2009

[3].Oyague, F., Butterfield, C.P., Sheng, S.: *Gearbox Reliability Collaborative Analysis Round Robin* American Wind Energy Association WINDPOWER 2009 Conference Chicago

[4].Gründer, W.: Schlecht, B.: Schulze, *T.:* *Getriebeberechnung nach aktuellen wissenschaftlichen Erkenntnissen*, Dresdner Maschinenelemente Kolloquium 2007

[5].Lenssen, S., Degtiarev, A., Godau, R., Kohlhepp, M., Hambrecht, R., Ribbentropp, A., Krull, F., Schemmert, S., *Durchgängige Prozesse zur Simulation komplexer mechatronischer Systeme am Beispiel einer Windenergieanlage*, Dresdner Maschinenelemente Kolloquium 2009

[6].Schlecht, B., Rosenlöcher, Th.: *Design and Analysis of Drive Trains in Wind Turbines and other large Industrial Applications*, Simpack-Academy Gross Schwansee 2009

[7].Schulze, T., Hartmann-Gerlach, Ch., Schlecht, B., Bauer, Ch.: *Anwenderorientierte Getriebeberechnung mit MDESIGN LVR^{planet} –Auslegung und Nachrechnung eines Windturbinenhauptgetriebes*, Dresdner Maschinenelemente Kolloquium 2009

[8].Schulze, Tobias: *Load distribution in planetary gears under consideration all relevant influences*. JSME International Conference on Motion and Power Transmissions May 13-15, 2009, Matsushima Isles Resort, Japan

[9].Schulze, Tobias: *Load distribution in planetary gears*. Danish gear society "Gearteknisk InteresseGruppe" 11th february 2010 at SDU in Odense, Denmark