MULTIBODY MODEL FOR PLANETARY GEARBOX OF 500 KW WIND TURBINE

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Summary The aim of the work is to simulate the loadings in a planetary gearbox of a wind turbine using a multibody program. A realistic wind turbine gearbox of a 500 kW wind turbine is examined using turbulent inflow data. An aeroelastic model of the wind turbine has been set up using the FLEX5-code (industrial standard software). The FLEX5 model as well as the developed multibody code has been verified from strain gauge measurements, giving e.g. the main shaft torque, and met mast wind data measurements. The realistic measurements on both input and output variables form an excellent base for studying the gearbox fatigue loads, the effect of wind turbulence on the power production/output torque on the highspeed shaft and for calibration and verification of the gearbox model.

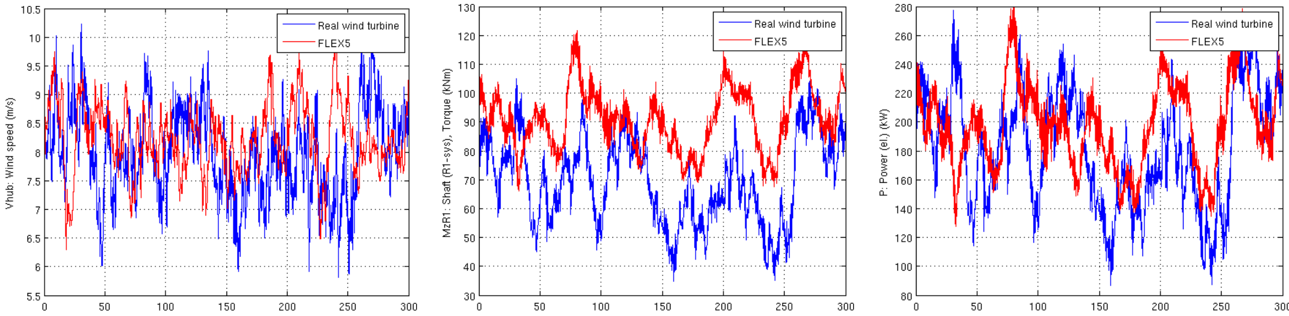
AEROELASTIC MODEL

In the past years various aeroelastic tools have been verified and used extensively by the wind turbine industry. Examples of some well-known codes are: GH Bladed, FAST, ADAMS, HAWC, HAWC2, BHAWC and FLEX (different versions exist). Although each tool have different modelling capabilities and characteristics, the FLEX5-code has been chosen for this project. The model can generally be described as a dynamic mechanical system with mass matrix M, stiffness matrix K, damping matrix C and a vector of generalized forces/external loads F_g:

$$M\ddot{x} + C\dot{x} + Kx = F_g \tag{1}$$

The F_g-vector contains the various loads acting on the blades and on other structures. The loads depend on wind speed, tip speed and on specific aerodynamic blade charateristics, such as lift and drag coefficients, which together with the local geometrical angles of attack govern the rotor aerodynamics. The loads are typically calculated using a model based on the unsteady Blade-Element Momentum (BEM) theory, [1]. Elastic blade deflection in flap- and edge-wise directions, due to turbulent wind inflow, cause variations in the calculated rotor torque as well as in the "apparent" wind speed felt by the blades and transmitted through the gearbox to the generator. A numerical solution to the mechanical problem can be found using e.g. a Runge-Kutta-Nyström scheme. The FLEX5 code is capable of describing the bending/torsion deflection of the blades and the tower using the most important eigenmodes. The model consists of 6 foundation DOFs (translational+rotational), 4 tower bending DOFs, 3 rotational DOFs for yaw, tilt and shaft, and 2 shaft bending + 1 shaft torsion mode. Additionally, for each of the 3 wind turbine blades, the deflections of the first two flapwise and edgewise eigenmodes are calculated.

In addition to wind turbine mechanical properties, generator data, moment of inertia, stiffness and damping coefficients etc, a realistic wind box (based on mean wind speed and turbulence variations) is used together with FLEX5. The wind model is based on a method [2], later described in [3]. Real wind data is taken from [4], where mean wind speed, wind direction (most undisturbed direction is used) and turbulence intensity are the most crucial parameters used to select time series from.



(a) Wind speed (b) Main shaft torque (c) Power production

Figure 1: Example of validation of wind turbine model input (FLEX5). Blue: Real measurements. Red: Simulated results.

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REALISTIC INPUT DATA AND MODEL VERIFICATION

As illustrated in Figure 1 the model allows a very good agreement between simulations and real measurements. A generally undisturbed mean wind speed of 8 m/s with turbulence intensity of 10% has been used. Imported 10-minute time series from [4] contain many important raw data channels of which the most important are: Produced power, nacelle wind speed and direction, turbine yaw angle and rotor torque and bending (from strain gauge - SG - measurements). From SG-data, exact derived quantities can be calculated, using a coordinate transformation. Further, exact shaft position and almost exact rotor speed (not taking torsion into account) are found from derived data channels. Finally, assuming correct offset and signal amplification of the SGs, leads to the torque at the low speed shaft, before the gearbox. After the gearbox, produced power is an accurate measure of whether or not the aeroelastic tool gives reasonable results. Figure 1 is an example showing 3 important comparisons, suggesting that the aeroelastic model is valid. Some validation effort is neccessary: From several time-series, it can be concluded that the simulations for a wide range of wind speeds are in good agreement with experimental data.

MULTIBODY MODEL OF PLANETARY GEARBOX

The dynamic gearbox model is based on [5] with a set of equations of motion described as

$$\begin{bmatrix} M & \Phi_q^T \\ \Phi_q & 0 \end{bmatrix} \begin{bmatrix} \ddot{q} \\ -\lambda \end{bmatrix} = \begin{bmatrix} g \\ \gamma \end{bmatrix} \tag{2}$$

Where M is the mass matrix, Φ_q is the Jacobian of constraint equations, q is the vector of generalized coordinates, λ is a vector of Lagrange multipliers. On the RHS, g is a vector of external forces (and torque from FLEX).
The multibody model in Figure 2 together with the aeroelastic tool, allows for complete drive train analysis, including examining gears, shafts, bearings and longitudinal/transverse reaction forces, for e.g. fatigue and stress/FEM analysis. For the last mentioned topics a realistic model of the constraints is necessary.

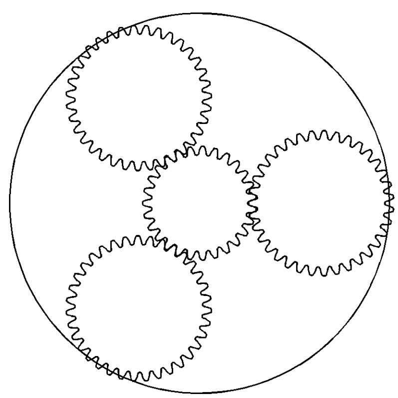

Figure 2: Simple multibody model consisting of 5 bodies (ring gear body illustrated as a circle).

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