Aeroelastic rotors in multibody simulation

Dr.-Ing. R. Schelenz,
Dipl.-Ing. T. Kamper
Dipl.-Ing. S. Flock
Overview

- Institute for machine elements (IME)
- Boundary conditions for the simulation
- Interconnections aerodynamic – rotor – drivetrain
- Simulation results
- Summary
- Future prospects

Aeroelastic rotors in Multibody Simulation
Institute for machine elements and machine design

Head of the Institute:
- Univ.-Prof. Dr.-Ing. G. Jacobs
- Chief-engineer transmission technology
- Chief-engineer tribology

25 scientific associates
- ca. 80% financed by third-party funds

27 non-scientific staff
- Machine-shop, Measurement-engineering, Administration

70 student assistants
- Research and teaching

Contact:
IME
Schinkelstr. 10
52062 Aachen
www.ime.rwth-aachen.de

Aeroelastic rotors in Multibody Simulation
Institute for machine elements and machine design

Headline: Mechanical Drive Train

Divisions

Tribology
- Slide bearings
- Rolling bearings
- Freewheels
- Coatings
- Lubricants
- Filter & Oil systems

Transmission Technology
- Machine Dynamics
  - MBS
  - Torsional vibrations
- FEM-Calculations
- Drivetrain-efficiency
- Acoustics
- Gearbox Systems

Aeroelastic rotors in Multibody Simulation
Interactions between the subsystems of a wind turbine

Aerodynamic system

Mechanical system (Focus on the Gearbox)

Electrical system

WEA Controller: DLL-Module
Interactions between the subsystems of a wind turbine

Expansion of the system-boundaries by taking into account an elastic tower connected to the foundation.

Aeroelastic rotors in Multibody Simulation
Aerodynamical load application

Measurement of the wind speed at one point:
- Wind measurement-pole / anemometer
- Conversion to hub height
- Alternative: Nominal wind speed & specification of the turbulence

Feedback aerodynamics & elasticity:
- Resulting incident flow
  - Rotorspeed of the rigid rotor
- Oscillating speeds of the elastic rotor

Wind field-generator:
- Ideally Parallel Flow
- Yaw-missalignment
- Altitude profile
- Stochastic distribution of rotor area

Aerodynamical forces Dynamical rotor torque
Flow effects taken into account

- **Blade Element Momentum Method (BEM)**
  - For the calculation of the aerodynamic forces on the blade profile the enhanced blade element momentum theory is used.
  - The required polars for the blade profiles are determined either by experimental analysis in wind tunnels or by simulations.
  - Good compromise between computing time and quality of the result.
  - By expanding BEM, dynamic processes can be taken into account.
Considered flow effects

- **Inflow due to Yaw misalignment**
  - The windspeed consists of a normal and a tangential component relative to the rotor plane
  - The revolving blade moves periodical in and against the direction of the wind
  - Due to the varying dynamic pressure the resulting force on the blade is subject to fluctuations
  - Furthermore the relative position of the blades to the wake of the leading blade varies with time

- **Dynamic inflow / stall**
  - The blade element method does not consider any time delay of the system response in case of a change of the inflow
    - By adding a „Dynamic inflow model“ to BEM, unsteady flow effects can be modelled
  - In case of a stall on the profile, the dynamic coefficients do not conform to the coefficients in the polar
    - Implementing of a „Dynamic stall models“
Considered flow effects

- **Influence of height**
  - Integration of different methods, to consider a change of the windspeed over the height of the wind energy plant.

- **Tower pile-up / Tower shadow**
  - The piling up of the flow in front of the tower leads to a massive reduction of the blade forces and hence the propulsive torque.
  - Representation of the flow around the tower as a (drag afflicted) cylinder flow
  - Oscillational excitation of the rotor blades

- **Tip Loss**
  - The pressure gradient on the rotor blade causes a compensating flow around the blade tip
  - A part of the kinetic energy can not be used for torque generation
Integration of elastic components

- The FEMBS-Interface in SIMPACK enables the integration of FE-Models
- The dynamical behavior of the component can be reduced to a set of eigenfrequencies by a modul reduction
- Reduction of the computing effort

First rotor-eigenmodes:

- Edge wise ($f_7 = 1.9$ Hz)
- Flap wise ($f_5 = 1.1$ Hz)

Nodes for the application of the aerodynamic loads

Rotor section
Modelling

- Wind turbine Controller
  - Active pitch control
  - Dynamic control of the generator-torque, the generator-state and the braking torque
  - Specification of the air-gap-torque by a characteristic curve of the doubly fed asynchronous generator

Integration of the wind turbine controller

- Rotor with elastic blades
- Flexible machine support
- Complete MBS transmission with elastic structure elements like rotorshaft or planet carrier

Integration of linear & bending modes with high relevance to the torsional DGF

Aeroelastic rotors in Multibody Simulation
Validation of simulation models (component wise)

Example: planet carrier (D ca. 1800 mm)

- Mode shape: torsional mode of the carrier faces
- Resonance frequency: $\Delta f < 2.5\%$ (10\%)
- Experimental results for structural damping

FE Model for elastic substructure:
> $f = 244$ Hz

Experimental modal analysis:
> $f = 236$ Hz
Example:

1. Rotor incl. control structure
2. Rotor shaft and rotor hub
3. Planetary gear
4. Spur gear with 2 gear stages
5. Coupling and brake disk with control structure for braking torque
6. Mass of generator incl. control structure for different load cases
SIMPACK model of a full wind turbine (focus on gear box)

SIMPACK model:

- Rotor and (flexible) rotor shaft
- Planetary gear
- Spur wheel section
- Elastic coupling and brake disk
- Generator
- (flexible) Machine support

Aeroelastic rotors in Multibody Simulation
Simulation of wind turbines
Bearing models for the simulation

linear

non-linear

non-linear

Lenssen, S., Schaeffler KG Simulation von Windenergieanlagen, ATK 2009

Aeroelastic rotors in Multibody Simulation
Including the wind turbine control

- In order to get a realistic operating performance, the logic control operations of the wind turbine manufacturer are implemented.

- Regulated variables for Power-control and control of the rotational-speed are
  - Pitch angle
  - Generator torque
  - Braking torque

- Most important variables which influence the procedures are:
  - Windspeed and –direction (Yawing)
  - Current rotational speed of the wind turbine
  - Stored operating control for different operating and emergency situations
Simulation results: Overview Run UP & validation

- 3D Wind field
- Controller:
  - start-up process
  - Pitch angle
  - Generator power control
  - Aerodynamic power control
  - Feedback \( n(t), M(t), P(t) \)

Comparison between IME Aeroelastik@SIMPACK and Flex5 (rotational speed of the rotor)
Simulation results part A: WEA Run UP

- Pitch angle
- Wind speed
- Rotor speed

Simulated time curves: pitch angle, wind speed, rotation speed of the rotor

Aeroelastic rotors in Multibody Simulation
Simulation results part B: WEA Run UP

Simulated time curves (aerodynamic rotor torque, rotational speed of the generator (actual/set), electric performance)
Simulation results

Simulation results match with the given measurement data of a Multi-Mega-Watt-wind turbine.

Torsional moment in the rotor-shaft in stationary operation
Summary

current activities at the IME

- **Summery**
- **Aeroelastic rotor modelling**
  - Good fit with results to reference tools used by wind turbine manufacturers (Flex5, Bladed)
  - Feedback on the transmission can be analysed in detail
  - IME is also using the Aerodyn Code @ Simpack Aero Module

- **Model validation**
  - In current bilateral projects:
    - Validation on component level (modal analysis)
    - Test rig measurements (gearbox teeth excitation)
    - Flex5 calculations are taken as reference
    - Measurements on the wind turbine itself (statistical comparison)
  - FVA 96/XVII: Research project „Modellfindung“

- **Future**
  - HDTC IME/RWTH: 1MW Inline test rig, ready to operate at the end of 2010
  - Planned: nacelle system testing at HDTC (turbine size as V52 or G52)
  - Enhanced aerodynamics & aeroelastics for future wind turbine aspects
Forecast: IME HDTC - Heavy Drive Train Center at RWTH Aachen Campus

• 1 MW In-Line testing station:

• System testing for WEA Nacelle
  • 1) Connected direct to fixed grid
  • 2) Real time Grid simulation on power level

• Start of Operation end of 2010

Controller

Nacelle
- $P_{\text{nom}} = 850 \text{ kW}$

Power control frequency converter

Generator & Frequency converter

Simulator for wind forces

Main bearing

Gearbox

Stolle Span
- $A = 14 \text{ m} \times 8 \text{ m}$
- $M = 800 \text{ to}$
- air suspension

Aeroelastic rotors in Multibody Simulation