Aero- and Hydro-Elastic MBS Wind Turbine and Component Simulation

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Aeroelastics

- Aeroelastic Simulation of Wind Turbines Using Coupled Multi-Body and Aerodynamic Approaches

Drive Train

- Design of a Wind Turbine Bedplate using Permas and advanced Drive Train Modeling

Offshore

- Simulation of Offshore Wind Turbines
Tradition

Ulrich Hütter: pioneer work on wind turbine design and GRP use (IFB)
F.X. Wortmann: airfoil design, LWT (IAG)
Test site Schnittlingen: UNIWEX (ICA)
Endowed chair of wind energy (SWE, since 2004)

Current Research Fields

- Operational behaviour
- Structural dynamics and design of offshore wind turbines
- Load monitoring and control
- Aeroelasticity (IAG & SWE)
- Aerodynamics and aeroacoustics
- Airfoil design, wind tunnel tests

Automated fibre composite manufacturing techniques
WindForS
The Southern German Wind Energy Research Alliance

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Aeroelastic Simulation of Wind Turbines Using Coupled Multi-Body and Aerodynamic Approaches

Stefan Hauptmann
SIMPACK Wind Turbine Aerodynamics

Rotor Aerodynamics
- 3 different aerodynamic approaches available

BEM
- „Simple but fast“
- Airfoil table required
- Industry standard
- Commercially available within SIMPACK
- First interface: 2006

Lifting Line-Method
- „More advanced, medium simul. time“
- Airfoil table required
- Soon available in SIMPACK (ECN)

Computational Fluid Dynamics
- „Very advanced, very high comp time“
- Direct calculation
- Limited industrial application so far
- Use for calculation of airfoil tables possible
Fluid-Structure Coupling (e.g. MBS/CFD)

**Fluid**

\[ Q^n \rightarrow Q^{n+1} \rightarrow Q^{n+2} \]

\[ t^n \rightarrow t^{n+1} \rightarrow t^{n+2} \]

**Structure**

\[ Q^n \rightarrow Q^{n+1} \rightarrow Q^{n+2} \]

Load projection on beam elements

Loads on element nodes (principle of virtual disp.)

Conversion of deformations to quarter chord line

Calculation of deformation

Blade structure

SIMPACK beam model

CFD solver

FLOWer

Grid deformation

Loads calculation

SIMPACK WT model

SIMPACK blade model with deformation

Conversion of deformations to quarter chord line

SIMPACK blade model
Pitch Error Simulated Using a CFD Solver

Aerodynamic simulation (CFD URANS): (no structural dynamics)

- Pitch angle of Blade 1
  - Constant misalignment of 8° towards feather

Flow field: equally pitched blades
Flow field: pitch angle blade 1 = 8°
Pitch Error Simulated Using Lifting-Line Method

Aeroelastic simulation: (flexible rotor blades considered)

- Pitch angle runaway Blade 1
  - +7.3° for 10 seconds
- Comparison of Lifting-Line against BEM method

[Figs. SWE - Universität Stuttgart]
Design of a Wind Turbine Bedplate using Permas and advanced Drive Train Modeling

Thomas Hecquet
Derivation of local Loads for Bedplate Optimisation

- Creation of a basic model under SIMPACK (Flex5 alike): „stage 1“
- Load simulations (at different design load cases)
- Derivation of global loads to component loads (e.g. assuming stiff components) used for the topology optimisation of the nacelle bedplate

[Fig. E.Hau - Windkraftanlagen]
Optimised Component Design with FEM and Integration in MBS

- Topology Optimisation of the bedplate and design of mechanical parts
- FEM modeling of the designed part
- Integration of the modal reduced FEM model into SIMPACK
- Load simulation considering the flexible bedplate

Cooperation with Intes (FEM Software Permas) www.intes.de

From bedplate optimisation to the consideration of its flexibility in the overall wind turbine
Detailed modeling of drive train with SIMPACK

- Influence of the modelling is being assessed both
  - In the frequency domain (modal analysis)
  - In the time domain (comparison of loads or displacements for different design load cases)

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**Horizontal Displacement of the main bearing under horizontal loading (thrust force as step excitation): „stage 1“ with rigid and flexible bedplate**

**Comparison of the horizontal forces between the tower top and the nacelle at the rigid and flexible models, turbine being loaded by a wind at constant speed**
Multi-torsional gearbox model and further improvements

More detailed modeling of the gearbox

- Multi-torsional
- Consideration of gear tooth stiffnesses (with FE14)
- Consideration of shaft stiffnesses (with FE12)
- The advanced multi-torsional Gearbox model is mounted on the flexible bedplate

3D View of the Nacelle Model with Flexible bedplate and the advanced gearbox model [Fig. SWE – Universität Stuttgart]
Simulation of Offshore Wind Turbines

Denis Matha
Introduction
Offshore Wind Energy Overview

2010: 2,946 MW
2020: 40,000 MW (EU Goal)
Introduction
Classification Offshore Wind Energy Support Structures

Onshore
Shallow Water 0m-30m
Transitional Depth 30m-60m
Deepwater 60m+

System Complexity

Statoil Hywind
Principle Power
Sway

[Fig.: NREL] [Fig.: Statoil] [Fig.: Principle Power] [Fig.: SWAY]
Introduction
Challenges for Simulation of Floating Offshore Turbines

**Coupled aero-hydro-servo-elastic interaction**

- **Wind-inflow:**
  - Discrete events
  - Turbulence
- **Aerodynamics:**
  - Induction / Downwind designs
  - Wake interaction
  - Yawed inflow
  - Dynamic stall
- **Structural dynamics:**
  - Gravity / inertia
  - Elasticity
  - Anchors / Moorings
- **Control system:**
  - Yaw, torque, pitch
- **Waves:**
  - Regular
  - Irregular
- **Hydrodynamics:**
  - Diffraction
  - Radiation
  - Hydrostatics
SIMPACK Offshore
Hydrodynamics Force Element

- User Force Element
- HydroDyn (NREL), modified by SWE for coupling with SIMPACK
- Validated with OC3 Phase IV results
- Validated with FAST HydroDyn Simulations
- Experimental validation planned
**INPUTS-1**
Platform Properties and Wave Conditions

**INPUTS-2**
Frequency dependent hydrodynamic matrices

**INPUTS-3**
Platform Marker Kinematics

**OUTPUT**
Hydrodynamic Forces and Moments on Platform
SIMPACK Offshore
MBS Mooring System

- Non-linear MBS Mooring Line
- Integrated FOWT system
  Simulation with full coupling

New User Force Element:
- Hydrodynamic forces computed with modified Morison Equation
- Validation with quasi-static model
- Multiple possible applications

(Figs. SWE - Universität Stuttgart)
OC3 Hywind Floating WT System

Aero-hydro-servo-elastic Simulation in SIMPACK:
- Flexible blades & tower
- Torque & Pitch control
- Moorings
- Waves
  - $H_{s,\text{wave}} = 6\, \text{m}$
  - $T_{p,\text{wave}} = 10\, \text{s}$
  - $V_{\text{wind}} = 8\, \text{m/s}$
Thank You For Your Attention

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IAG