Nacelle Test Benches for Model Validation

Joerg Berroth,
Laiye Bi, Daniel Matzke, Alexander Werkmeister,
Ralf Schelenz, Georg Jacobs
Outline

- Wind Turbine System Analysis at CWD
- Full Scale Nacelle Test Benches
  - 1 MW nacelle test bench – lessons learned
  - 4 MW nacelle test bench at CWD
- Conclusion
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Center for Wind Power Drives
Interdisciplinary wind energy research at RWTH Aachen University

Directorate: Prof. Abel, Prof. Brecher, Prof. De Doncker, Prof. Hameyer, Prof. Monti, Prof. Jacobs, Prof. Schröder

CTO: Dr. Schelenz

Prof. Abel Controls
Prof. Brecher Gears
Prof. De Doncker Power Electronics
Prof. Hameyer Generators
Prof. Monti Grids
Prof. Schröder Aerodynamics
Prof. Stich Logistics

Prof. Jacobs Chair for Wind Power Drives
Dynamic Wind Turbine Analysis
by means of Multi-Body-Simulation

Aerodynamic system

Mechanical system

Electrical system

WT Controller

Source: VEM
Design Load Calculation by means of MBS with Simpack

Pre Processing

Design Load Case (DLC) Selection

<table>
<thead>
<tr>
<th>DLC</th>
<th>Operational Conditions</th>
<th>Windtype</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Power Production</td>
<td>NTM</td>
</tr>
<tr>
<td>1.3</td>
<td></td>
<td>ETM</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td>...</td>
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</tbody>
</table>

Windfile generation (NREL TurbSim)

Load calculation Control Matrix

<table>
<thead>
<tr>
<th>DLC</th>
<th>Kat</th>
<th>Windgesch.</th>
<th>Windfeld.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1a</td>
<td>'1'</td>
<td>3</td>
<td>'U1/Project'</td>
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</table>

Load Calculation with Simpack

Post Processing

- Variability in Model detail
- Calculation done according to IEC 61400-1 (tested with 2000 DLC)
- ~10min/600s simulation time for standard DLC model

fully automated load calculation process
Pitch System
MBS Model for Pitch System Load Calculation

[Ber14]

Turbine control via co-simulation

Force elements:
- co-simulation i/o
- Aerodyn
- tooth contact

Rigid body
Flexible body
Tooth backlash – Simulation and Measurement

Plot over rotor azimuth:

Pitch motor torque [Nm]

Rotor azimuth angle [°]

Field measurement
Simulation w/o gearbox
Simulation with gearbox

Tooth backlash strongly depends on dynamical changing of blade mass loads
Additional Control Systems: Trailing Edge Flaps
Wind Turbine Acoustics by means of MBS

- MBS tooth contact (FVA)
- Reduced flex structures for MBS
- Validation of flex models

In cooperation with: Bosch Group

slide 10  Nacelle Test Benches for Model Validation  Berroth et al. | Simpack Wind and Drive Train Conference | Hamburg | 07/10/15
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- New platform generations come with new drive concepts that will be tested before pushing a first prototype turbine
- Full-scale nacelle test is the only way to create comparable, controllable and reproducible load condition
- Several research facilities around the world have adopted this approach
System Test of WTG Drive Train
CWD Approach: Same Input & Output Loads as on the Tower

6 DOF:
- Rotor blade
- Rotor speed
- Pitch angle
- Tower shadow

wind loads T, F

3D wind field

Research topics:
- Reliability
- Availability
- Efficiency
- Costs
- Certification
- Grid

+ All degrees of freedom
+ Defined loads
+ Good observability
+ Time scaling
- Effort

U, f
Gridloads

Smart-Grid
- FRT
- EU-Grid
- US-Grid

current and voltage drop
4 MW demonstrator WTG nacelle test bench
Investigation & proof of WTG HIL testing techniques
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1MW Full Scale Nacelle Test Bench

1MW Prototype Test Bench at IME Test Center

- Proof of concept for real-time Hardware in the Loop testing with original WTG controller
Virtual 1MW Full Scale Nacelle Test Bench – MBS Model

Detailed MBS model of the test rig with nacelle drive train and structure

- Drive train and support structure modeled flexible to investigate overall stiffness
- Co-Simulation via SIMAT: All hardware-in-the-loop control elements integrated
Modeling of Hydraulic Dynamics involved in NTL application

Realized via co-simulation between Simpack/Simulink

- The control valves have fast responses
  - ca. 40Hz at 25% load
- Hydraulic spring has also rel. high frequency
  - 30.1Hz in the mid of stroke
- A single actuator with rigid support and ideal joints has slightly degraded freq. response
  - 19.6Hz at 45deg phase point with active control
- The main dynamics is not determined by the actuators
Validation of Drive Train model

Example modal fitting:
Motor speed $n=500$ rpm;
Thrust: $F_m=100$ kN, $F_a=\pm4$ kN
Sin-Sweep 0 - 30 Hz with 0.3 Hz/s

1st drive train bending mode at 15.38 Hz

2nd drive train bending mode at 22.09 Hz
Physical Characteristics: Test Bench vs. Real Turbine

- **RTPS - Slave Drivetrain**
  - IM Rotor
  - Slave Gearbox
  - LSS and couplings

- **DUT - V52 Nacelle (Drivetrain)**
  - V52 Gearbox
  - Generator Rotor

**Very large inertia**

**Highly flexible**

**Blade modes:**
- 1\textsuperscript{st}/2\textsuperscript{nd} flap
- 1\textsuperscript{st}/2\textsuperscript{nd} edge

**Time variant**

Area of yellow represents torsional moment of inertia $J$
(all equalized to low speed shaft)
Simpack Virtual Test Bench and Turbine Model for control design

- Inertia and stiffness emulation plays an important role for closed loop nacelle testing
**Improve Torque Load Bandwidth by Design Evolution on virtual test bench**

**Comparison of 1st dominant test bench eigenvalue for different test bench configurations**

- **Design 1:**
  Base

- **Design 2:**
  Direct drive as test bench drive motor

- **Design 3:**
  Stiffer coupling NTL/prime mover

- **Design 4:**
  Design 2+3

![Diagram showing the comparison of eigenvalues for different test bench configurations.](image)
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Public Joint Research Project „FVA Nacelle“

- Investigation on the impact of different system states on 6 DOF loads of system components and single machine elements
- Validation of drive and machine element models to help avoid design driven component failures
- Test Turbine: 2.75 MW field turbine
  - Turbine has been disassembled on site and shipped to Aachen
  - Complete Drive train is maintained
  - Main bearings are changed
  - Gearbox will be modified
  - Generator and Converter System will be updated by SIEMENS
Modelling and Simulation in the framework of FVA Nacelle Project

Global SIMPACK Simulation model for derivation of internal loads for model validation of heavy drive trains

Global MBS Model

Component Internal Forces

Validation with Nacelle Tests

Machine element models

FE based tooth contact models (FVA)

FE based bearing models

Simpack flex gears

Model Parameters
MBS Drive Train Model

MBS Model: Test Bench/Nacelle Drive Train First Torsional Mode
Conclusions

- At the CWD, current research incorporating Simpack focuses on
  - Entire system dynamics of Wind Turbines,
  - Subsystem dynamics (Pitch system, Trailing Edge Flaps)
  - Gearbox Dynamics and Acoustics
  - Full Scale Nacelle Test Benches

- The flexibility in terms of topology definition, user routines and co-simulation interfaces makes Simpack the preferred MBS framework.

- The 4MW Nacelle test bench at CWD will enable investigations on dynamic drive train loads and help to validate simulation codes.
- Simpack is used for building “Virtual Test Benches” (VTB) to support the control design of test benches.
- Loads from VTB - validated with test bench measurements - will be used to validate FVA Workbench drive train calculation tools.
Thank you for your attention.

joerg.berroth@cwd.rwth-aachen.de
laiye.bi@cwd.rwth-aachen.de
daniel.matzke@cwd.rwth-aachen.de
alexander.werkmeister@cwd.rwth-aachen.de

ralf.schelenz@cwd.rwth-aachen.de
georg.jacobs@cwd.rwth-aachen.de
References


