Analysis of main influencing factors on critical loads at transmission bearings and identification of critical operation states

International Conference Wind Turbine Bearings 2018, Hamburg
<table>
<thead>
<tr>
<th></th>
<th>Agenda</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong></td>
<td>Motivation and project</td>
</tr>
<tr>
<td><strong>2</strong></td>
<td>Approach of analysis</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>Sensitivity analysis concerning different impact factors on bearing loads</td>
</tr>
<tr>
<td></td>
<td>Static loads at hub flange</td>
</tr>
<tr>
<td></td>
<td>Dynamic loads at hub flange</td>
</tr>
<tr>
<td></td>
<td>Different bearing clearances of planet and planet carrier</td>
</tr>
<tr>
<td><strong>4</strong></td>
<td>Analysis of specific operation states</td>
</tr>
<tr>
<td><strong>5</strong></td>
<td>Summary</td>
</tr>
</tbody>
</table>
Wind turbine failures
Long down time periods are caused by bearing outages

Wind turbine failures
- Yaw System: 25%
- Elektrical: 8%
- Blade: 3%
- Nacelle: 3%
- Generator: 3%
- Gearbox: 59%

Gearbox failures
- Bearing: 67%
- Others: 33%

Bearing failure modes
- Axial cracks 71%
- Spalling 23%
- Pitting 6%

Affected bearing types
- Planetary bearings 10%
- HSS bearings 70%
- Other bearings 20%

Failures are caused by dynamical mechanical overloads
Dynamic loads at these stages are still not sufficiently well known

Dynamic load analysis using multi body simulation
Approach of the performed analysis

Simulations with varied wind profiles and special operation states
- Mean wind velocity: 17.5 m/s
- Turbulence intensity: 0.12
- Extreme loads occur during special operation states: gusts, emergency stops etc.
- Determination of realistic load values, amplitudes and frequencies

Determined load values at hub flange
Settings for Sensitivity analysis that is based on Design of Experiments
Dynamic load analysis using multi body simulation
Approach of the performed analysis

1. Wind loads
2. Main shaft loads
3. Bearing loads

Varying torques and forces at hub flange

Analysis of radial and axial loads at each bearing series of planetary and high speed shaft stage
Experimental design and execution:

- Influence of four factors are analysed:
  - $F_{\text{thrust}}$
  - $M_{\text{drive torque}}$
  - $M_{\text{tilting}}$
  - $M_{\text{yaw}}$
- Simulation plan is based on DoE
  - Factors are set on two different load levels

Evaluation of simulated experimental design:

- Resulting radial bearing loads are summed up separately for all simulation runs with the higher setting of a factor and for simulation runs with the lower setting of the factor
- Evaluation is visualized by effect diagrams
- Evaluated simulations with the lower factor value are labeled with a minus “-“
- Evaluated simulations with the higher factor value are labeled with a plus “+“

Load analysis at planetary and HSS stage

- Position of planet for load analysis at the planetary stage is 270°

Static input loads at hub flange

\( M_{\text{drive trq}} \) is main influencing factor of all static loads

Mean of radial bearing loads at planetary stage by different factor settings:

- Changing the setting of \( M_{\text{drive trq}} \) leads to an increasing radial bearing load of about 40 kN at each bearing series at planetary stage
- No significant influence of static loads of \( M_{\text{tilting}} \) and \( M_{\text{yaw}} \)

Mean of radial bearing loads at HSS stage by different factor settings:

- Static loads of \( M_{\text{drive trq}} \) influence the rotor side bearing of HSS about 15 kN
- No significant influence of static loads of \( M_{\text{tilting}} \) and \( M_{\text{yaw}} \)
Experimental design static loads:

<table>
<thead>
<tr>
<th>$F_x$ [kN]</th>
<th>$M_{\text{drive , torque}}$ [kNm]</th>
<th>$M_{\text{tilting}}$ [kNm]</th>
<th>$M_{\text{yaw}}$ [kNm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>330</td>
<td>1600</td>
<td>500</td>
<td>200</td>
</tr>
</tbody>
</table>

Additionally impressed dynamic loads:

- dynamic $F_x$
- dynamic $M_{\text{drive \, trq.}}$
- dynamic $M_{\text{tilting}}$
- dynamic $M_{\text{yaw}}$

Planetary bearing loads by different amplitude settings of analysed factors:

- Changing the amplitude value of $M_{\text{tilting}}$ influences the load distribution at planetary stage.
- No significant influence of amplitudes of $M_{\text{drive \, trq.}}$ and $M_{\text{yaw}}$.
- Dynamic loads at hub flange does not influence mean of radial bearing load at HSS-stage.
Results of dynamic input loads at hub flange
Analysis with variegated bearing clearances

Planetary bearing loads by different amplitude settings of $M_{\text{tilting}}$ and additionally different settings for bearing clearances:

- Performing the dynamic simulation plan with different bearing clearances:
  - 1. Origin model
  - 2. Halving bearing clearance of planetary carrier
  - 3. Additionally halving bearing clearance of planet

- Reducing the bearing clearance of planetary carrier minimize the effect of $M_{\text{tilting}}$ at bearing series 1 and 4
- Additionally reducing the bearing clearance of the planet slightly increases the effect of $M_{\text{tilting}}$ at bearing series 1 and 4.
Results of dynamic loads at hub flange
Frequency analysis of radial bearing force

- \( f_{\text{drive torque}} = 0.28 \, \text{Hz} \)
- \( f_{\text{tilting}} = 0.28 \, \text{Hz} \)
- \( f_{\text{yaw}} = 0.28 \, \text{Hz} \)

- \( f_{\text{drive torque}} = 0.28 \, \text{Hz} \)
- \( f_{\text{tilting}} = 0.84 \, \text{Hz} \)
- \( f_{\text{yaw}} = 0.84 \, \text{Hz} \)

- \( f_{\text{drive torque}} = 0.84 \, \text{Hz} \)
- \( f_{\text{tilting}} = 0.28 \, \text{Hz} \)
- \( f_{\text{yaw}} = 0.28 \, \text{Hz} \)

- Variegated excitation frequencies of dynamic input loads at hub flange:
  - 0.28 Hz (1P Frequency)
  - 0.84 Hz (3P Frequency)

- Frequencies of drive torque affect the frequencies at the bearing stages of planet and HSS

- \( M_{\text{tilting}}, M_{\text{yaw}}, \text{and } F_{\text{thrust}} \) do not affect frequencies at bearing stages
Relevant input loads with highest impact on resulting bearing loads are evaluated.

Special operation states: gusts, grid loss, emergency stop

Wind loads

Load classification of special operation states

Electrical loads

Outlook: specific test loads

Test cycle “Bearing Robustness Test” at WT-Bearing Center.NRW

Consideration of special operation states

Main shaft loads

F_radialplanet

F_radialHSS

Specific load characteristics

Load [-]

Time [-]
Summary
Influences on bearing loads & analysis of operation states

Initial situation
- Economic efficiency of WT is burdened by early outages of roller bearings
- Majority of resulting down time periods is caused by bearing failures of planetary and HSS stage
- The project WT-Bearing Center.NRW focus on bearing outages of wind turbines by testing origin sized bearings

Main Results
- Main impact factors on bearing loads are evaluated:
  - Dynamic tilting torque influences the load distribution at the planetary stage
  - Drive torque has main impact on resulting bearing loads concerning load value, amplitude and frequency
- Highest load gradients occur during special operation states
  - Characteristics of these operation states are classified concerning min, max values of loads, frequencies and load gradients
  - Including load characteristics inside the Bearing Robustness Test by specific load gradients and values to the default load spectrum
- Bearing robustness test will be a standard test procedure for qualification and approval of rolling bearings of wind turbines
Thank you for your attention!