Joint Optimization of Noise & Vibration Behavior of a Wind turbine Drivetrain

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Source: www.vestas.com
Agenda

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ZF Wind Power – Global Footprint

A cooperation between Vestas® and ZF

More than 10,000 MW capacity for wind gearboxes

Gainesville, GA, USA
Start 2011
Production: 23,000 m²
Employees: 70
Product range: 2 MW
Capacity: 1000 MW
Opening: 2011
Designed according to ZF automotive standards

Lommel, Belgium
Start 2001
Production: 110,000 m²
Employees: 700
Product range: up to 6 MW
Capacity: 5500 MW

Coimbatore, India
Start 2008
Production: 95,000 m²
Employees: 592
Product range: up to 3 MW
Capacity: >3000 MW

Tianjin, China
Start 2009
Production: 95,000 m²
Employees: 128
Product range: up to 3 MW
Capacity: >1000 MW
Vestas

Vestas in brief

The only global wind energy company

Vestas locations around the world

Vestas has a unique global reach in sales, installation and manufacturing

External analysts have Vestas as a clear No. 1 in 2013 with a market share (onshore and offshore) of more than 13%

Source: Vestas: Corporate Presentation2014Q1;
Introduction

For the development of a new gearbox Vestas and ZFWP decided to cooperate in the drive train development process

- starting from the design stage
- working together in a structured way
- in noise and vibration challenges:
  - Local tonality requirements e.g. Germany
  - Reduction of tonal masking because of:
    - Possibility to use wind turbines at wind sites with low average wind speed
    - Lower cut-in speed of wind turbines to increase power production
  - Cooperation by means of:
    - Knowledge sharing
    - Model sharing
    - New methods

Product development process in case of Changes

Influence

Start point

Milestone 1

Milestone 2

…

Milestone n

Increasing knowledge about dynamic behavior of system and gearbox

resources

information

Time
Mechanical noise

How does mechanical noise (tonality) in a wind turbine occur?

Transfer path of mechanical noise (gearbox as example)

Source: gear mesh, (bearings, pumps)
Structure borne transfer path inside / outside gearbox
Airborne radiation by gearbox / by other components
Mechanical noise

- Sources: gearbox, generator, cooling fans, …
- Radiator: blades, tower, …
- Primarily tonal content, not determining WT overall SPL

Petitjean et al. (2011) [1]
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Workflow

Simulations

Identification of most important eigenfrequencies

Consideration of different criteria
• Order meshes
• Rotational speed histogram
• Low noise modes

Classification of potential risks

• Prediction of gearbox quality
• Validation of gearbox model

• Estimation of tonality risks in the field

Frequency

Speed
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Models: Gearbox

Flexible planet carrier assembly: reduced FE model

Flexible shafts: reduced 1-DOF FE model

Flexible housing assembly: reduced FE model

Gears:
- Rigid bodies
- FE 225

Accelerometer master nodes

Linearized bearing stiffnesses: 6x6 matrices
Models: development process

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- Torsional DOF

- 6 DOF
- Flexible gearbox housing
- Rigid planet carriers
- Old bearing stiffness’s

- 6 DOF
- Flexible gearbox housing
- Flexible planet carriers
- Bearing stiffness’s from suppliers

- Update of model parameters by validation
Models: Wind Turbine

- Main bearing stiffness behavior is captured by a U-force (developed by Vestas)
- Blade created with Simpack Rotor Blade generator (extended beam model)
- Main shaft as flex body
- Combined Gallery-Main frame- Tower flex body
- Matlab Simulink model for including wind turbine controller
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Models: Test rig

- Gearboxes back-to-back
- Flexible low speed shafts: reduced FE model
- Flexible cardan shafts: reduced FE model
- Generators: rigid bodies
- Flexible assembly of cassette with central bearing and blocks: reduced FE models
Results

Cooperation between WT manufacturer and GBX supplier is necessity because transfer path consists of gearbox and wind turbine.

Proof: Comparison of order slices obtained from speed run-up simulations:

- Vibration amplitudes in wind turbine tend to decrease compared to test rig.
- Dynamics between test rig and wind turbine change.

⇒ System approach required.
Results

Cooperation between WT manufacturer and GBX supplier is necessity because transfer path consists of gearbox and wind turbine

Source: gear mesh, (bearings, pumps)
Structure borne transfer path inside / outside gearbox
Airborne radiation by gearbox / by other components

Estimation of tonality risks
⇒ simulated FRF’s from gear pairs to velocities of various rotor blade stations with system model
Model validation

Gearbox model validation:
- Experimental Modal Analysis (EMA)
- Measurements on back-to-back test rigs
  - Speed run-ups at constant loading
  - Constant speed – constant load

Wind turbine model validation:
- Measurement on system test rig (ongoing)
- Field Measurement on prototype turbine (is planned)
GBX model validation - EMA

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- Gearbox on support structure on rubber blocks
- 2 electromechanical shakers
- 294 accelerometer positions
- Tri-axial accelerometers
GBX model validation - EMA

- Correlation analysis based on MAC
- Model updating:
  - Rubber bushing stiffnesses
  - Interconnection stiffnesses between support and gearbox
  - Gear contact stiffnesses
GBX model validation – back-to-back test rig

Validation of the test set-up model ongoing
WT model validation – system test rig

Test of the drive – train and supporting structure:
- Gearbox
- Main frame
- Main shaft
- Supporting structure to yaw system

Vibration measurements:
- 11 accelerometers on gearbox and wind turbine main frame
- Measurement results will be compared with
  - Gearboxes of other suppliers
  - Supplier test results
  - Turbine results
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WT model validation – prototype turbine

Vibration measurements
• 22 Tri-axial accelerometers in the nacelle

Noise measurement:
• Microphones:
  • Inside the nacelle close to gearbox
  • Outside the turbine according to standard noise regulations (IEC)
Conclusion

• Cooperation between WT manufacturer and GBX supplier is necessity because transfer path consists of gearbox AND wind turbine
  • Differences in dynamic behaviour of gearbox on test rig or in wind turbine ⇒ system approach required
  • Estimation of tonality risks ⇒ simulated FRF’s from gear pairs to velocities of various rotor blade stations with system model

• Thorough approach has been used:
  • Gradual build-up of state of the art models
  • Experimental validation of models to increase confidence level

• Vestas and ZF Wind Power join forces from early design stage to optimize N&V behaviour of wind turbine drive train
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Source: www.vestas.com