Driveline and Chassis Technology

Design of wind turbine gearboxes with respect to noise

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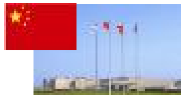
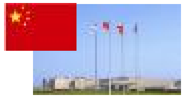
Wind Power Technology

A brand of ZF

Agenda

1.	**ZF Wind Power**
2.	Mechanical noise of wind turbines
3.	Gearbox design for low noise and vibrations
4.	Research project ALARM
5.	Conclusions

Combination of ZF and Hansen

	ZF	Hansen Transmissions	ZF + Hansen Transmissions
Customers	Vestas	Vestas, SUZLON, Gamesa, REpower Systems, SIEMENS, SINOVEL 华锐风电	Vestas, SUZLON, Gamesa, REpower Systems, SIEMENS, SINOVEL 华锐风电
Products	 2 MW	 1,5 MW to 6,15 MW	
Regions			
Production Locations	 Gainesville, USA	 Lommel, Belgium  Coimbatore, India  Tianjin, China	 Gainesville, USA  Lommel, Belgium  Coimbatore, India  Tianjin, China

Source: ZF; Hansen Transmission Annual Report 2011, 31.03.11 and Annual Report 2010, 31.03.10

The Business Unit Wind Power Technology is part of the Industrial Technology Division of ZF

ZF Friedrichshafen AG

Shareholders: 93.8 % Zeppelin Foundation and 6.2 % Dr. Jürgen and Irmgard Ulderup Foundation

Board of Management:

- **CEO, Market**
- **Finance, Controlling, IT, Process Management**
- **Human Resources**
- **Materials Management**
- **Operations and Technology**
- **Compliance [1]**
- **Die Casting Technology[2]**
- **ZF Services [3]**

Division – Powertrain Technology

- Transmissions
- Axle Drives
- Powertrain Modules

Division – Chassis Technology

- Chassis Systems
- Chassis Components
- Rubber & Plastics
- Suspension Technology

Division – Commercial Vehicle Technology

- Truck & Van Driveline Technology
- Bus Driveline Technology
- CV Axle Systems
- CV Chassis Modules
- CV Damper Technology
- CV Powertrain Modules

Division – Industrial Technology

- Construction Machinery Systems
- Agricultural Machinery Systems
- Material Handling Systems
- Test Systems
- Special Driveline Technology
- Electronic Systems
- Marine Propulsion Systems
- Aviation Technology
- Wind Power Technology

Joint Venture – Steering Systems [4] 50 %

- Passenger Car Steering Systems
- Commercial Vehicle Steering Systems
- Passenger Car Steering Columns
- Global Aftermarket

Legend:

- Board of Management
- Organizational unit
- Integration of Hansen Transmissions
- Partial activities in wind power

1) linked to CEO
2) linked to Materials Management domain
3) linked to Market domain

4) ZF Lenksysteme GmbH is a joint venture between ZF Friedrichshafen AG and Robert Bosch GmbH.

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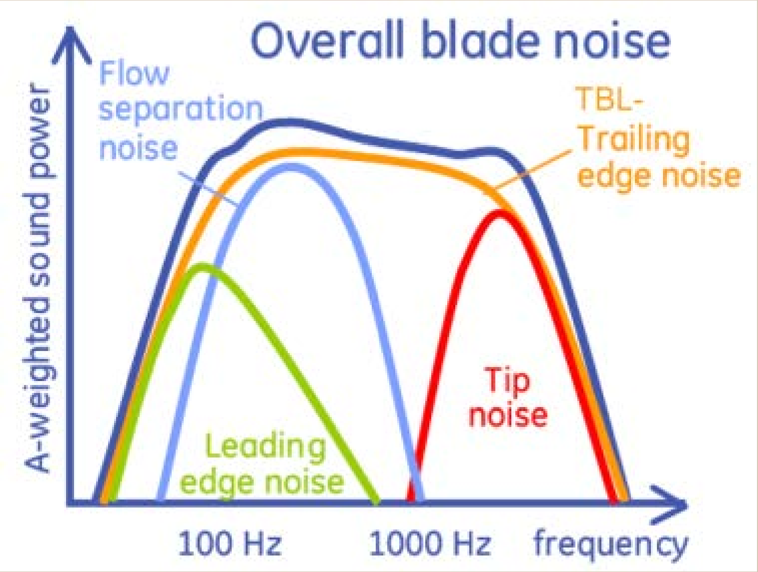
Mechanical noise of wind turbines

Frequency spectrum of wind turbine noise sources

1. <u>Aerodynamic noise</u>

- source = blade motion in air
- primarily broadband - e.g. total SPL = 105 dB(A) (turbine at rated wind speed)

Ramachandran et al. (2012) [2]



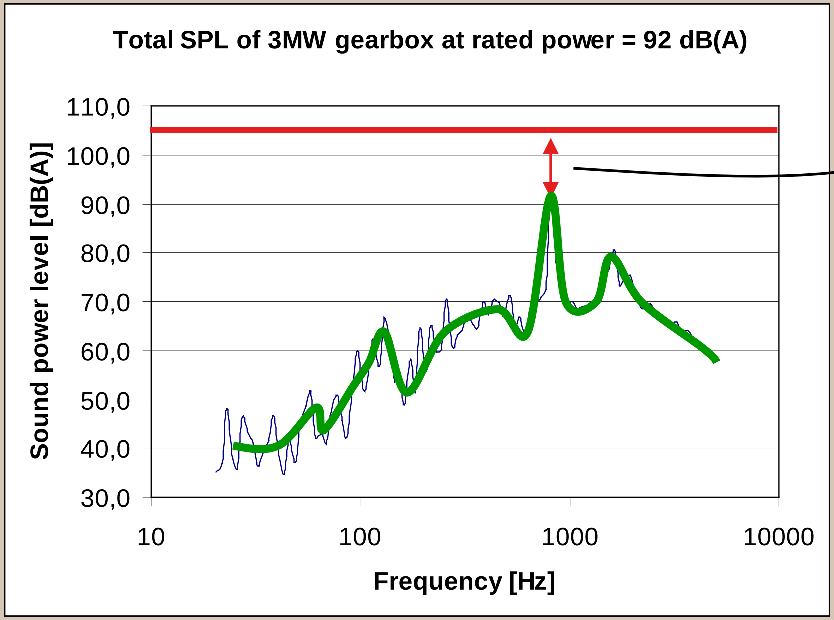
Petitjean et al. (2011) [1]

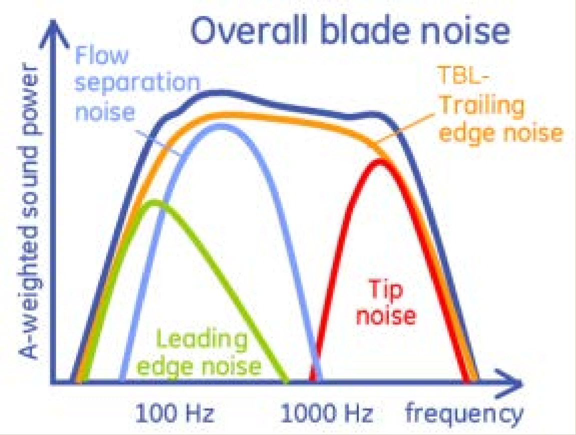
Mechanical noise of wind turbines

Frequency spectrum of wind turbine noise sources

2. Mechanical noise

- sources: gearbox, generator, cooling fans, …
- primarily tonal content, not determining WT overall SPL

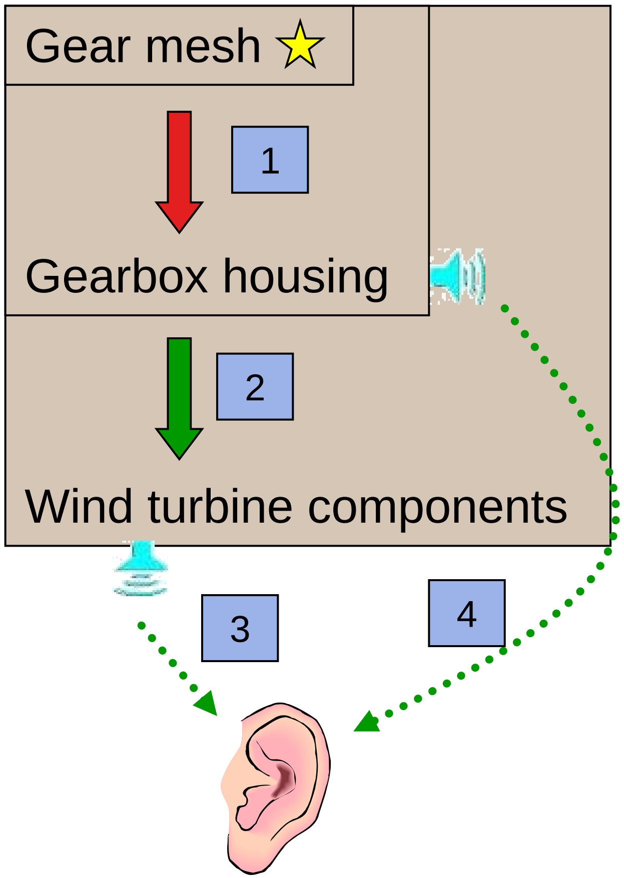


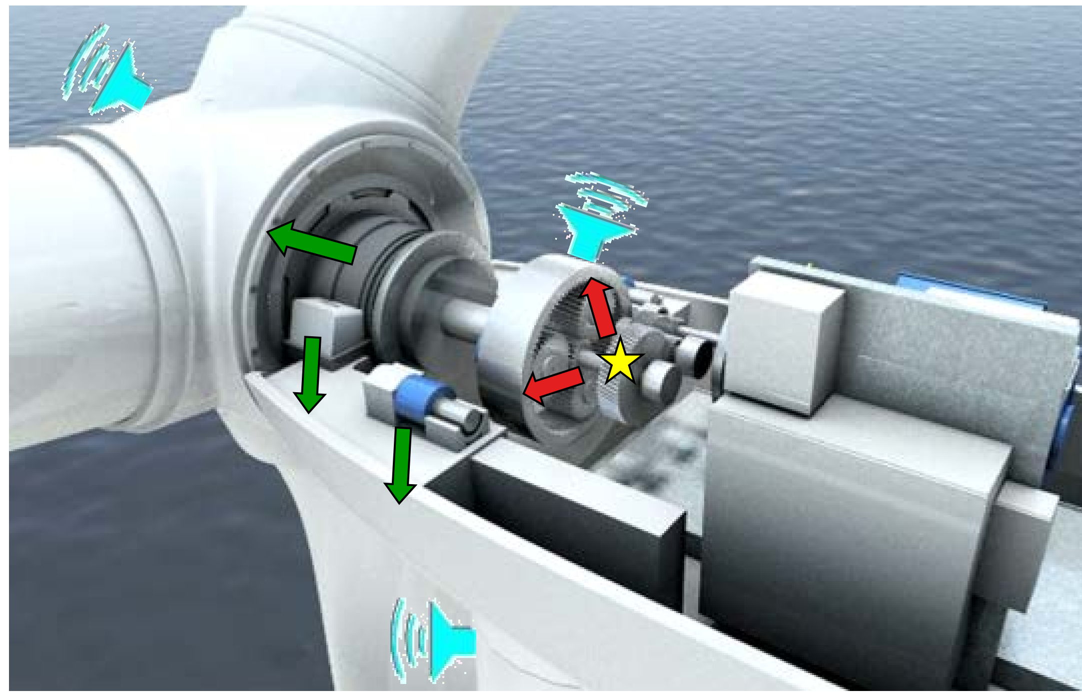


Petitjean et al. (2011) [1]

Mechanical noise of wind turbines

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

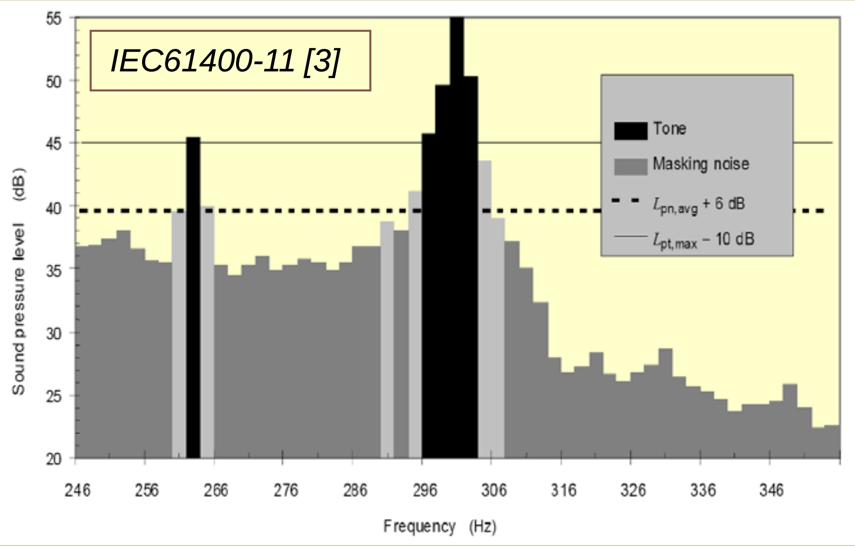
Mechanical noise of wind turbines

Potential annoyance

Annoyance depends on noise level of other sources (a.o. aerodynamic, background)

1. <u>tonality:</u>

   distinguishable tone is audible



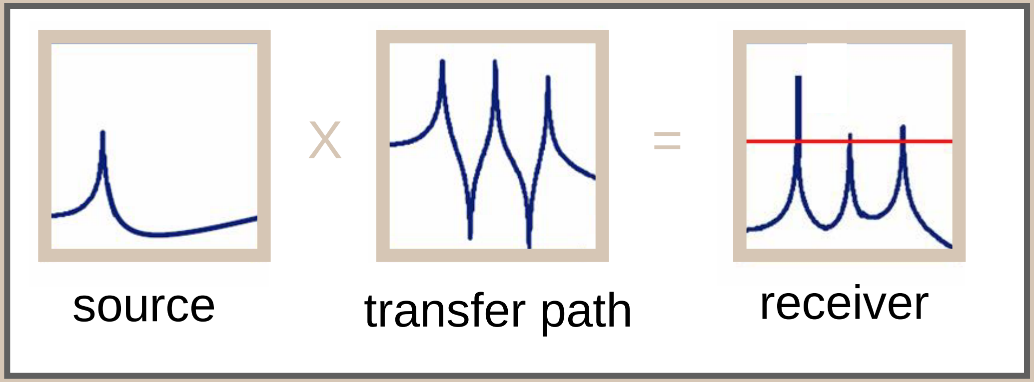
2. (overall WT sound power level dominated by mechanical noise)

Mechanical noise of wind turbines

Measures / solutions for annoyance of mechanical noise

A. Design "first time right"

- reduce source level
- optimise transfer path (avoid resonance / add damping)



B. Corrective actions (when needed)

- shift resonance (e.g. tuned absorber, change speed)
- add more damping (e.g. nacelle insulation)

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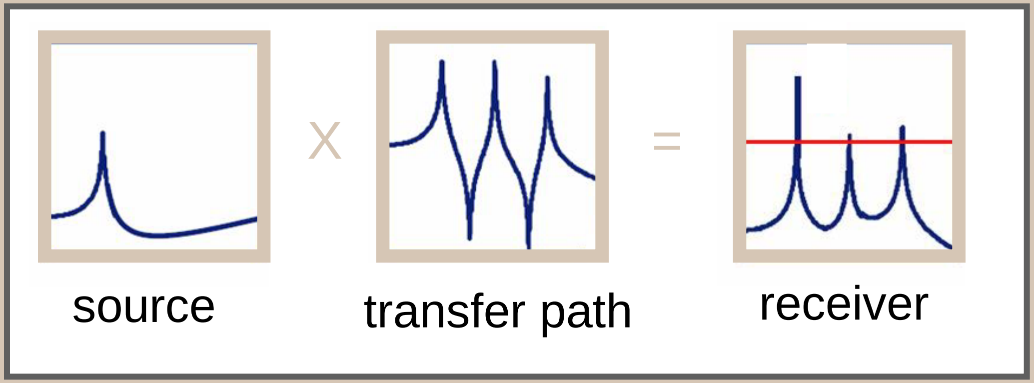
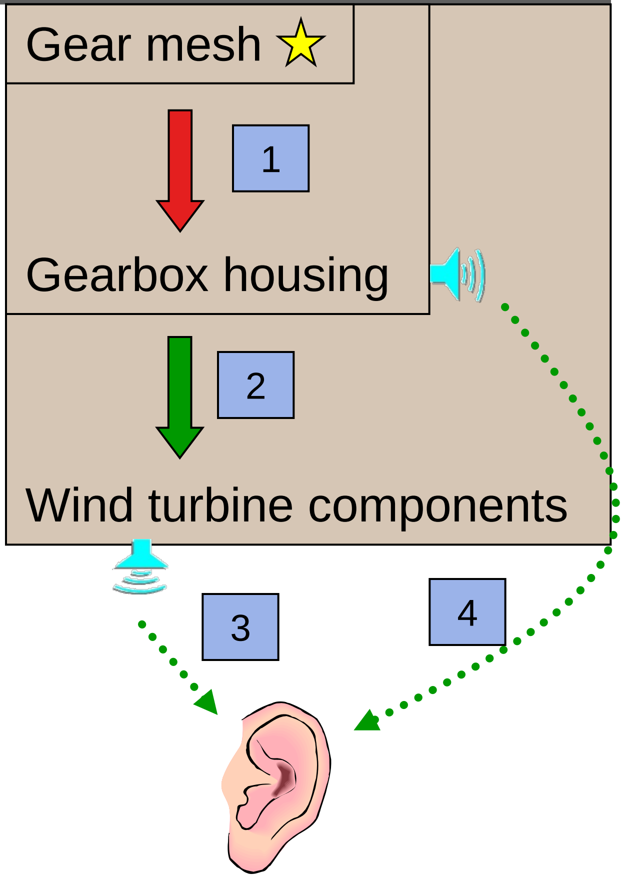
Gearbox design for low noise and vibrations

Challenges in “first time right” gearbox design

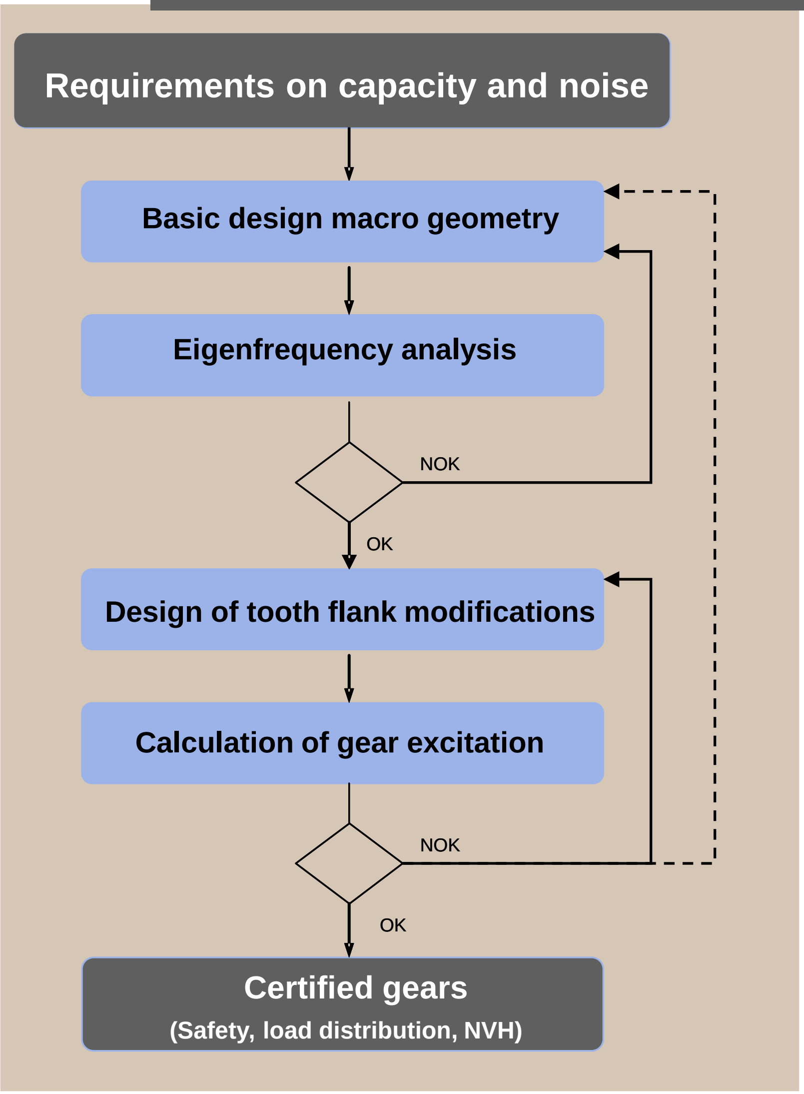
1. Reduce source level
   = reduce gear mesh excitation ☆
2. Optimise gearbox housing
   - structure borne [1]
   - airborne radiation
3. Integration in wind turbine [2] [3] [4]

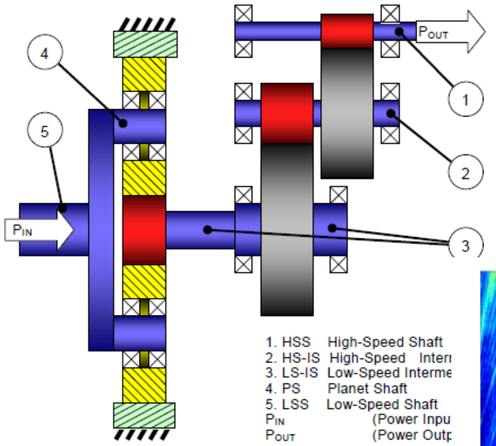


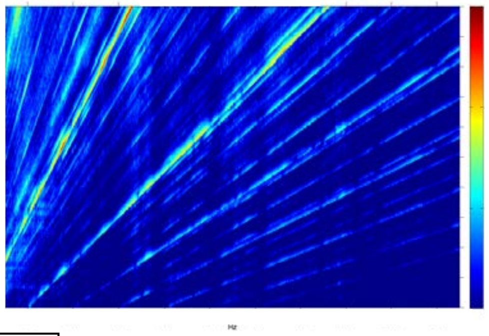


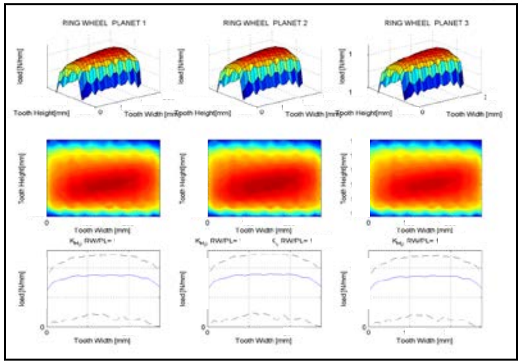
Gearbox design for low noise and vibrations

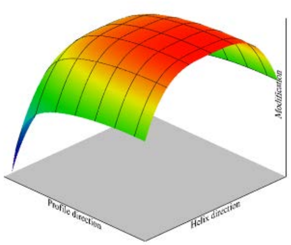
1. Excitation reduction through gear optimisation







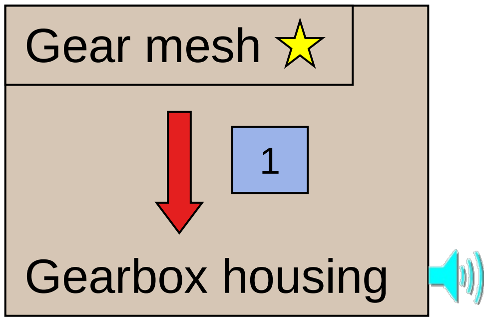




Gearbox design for low noise and vibrations

2. Transfer path optimisation: structure borne and airborne

Optimisation by virtual design assessment



<u>Simulation requirements:</u>

- Gear mesh model
- Transfer path structural model
- Radiation
  - structure borne at interfaces
  - airborne at housing

<u>Chosen solution:</u>

Multibody simulation for vibrations

Acoustic FE simulation for airborne radiation

Gearbox design for low noise and vibrations

2. Transfer path optimisation: structure borne and airborne

Structural multibody simulation model in SIMPACK

- Gear excitation forces

  SIMPACK FE-225

- Bearing forces

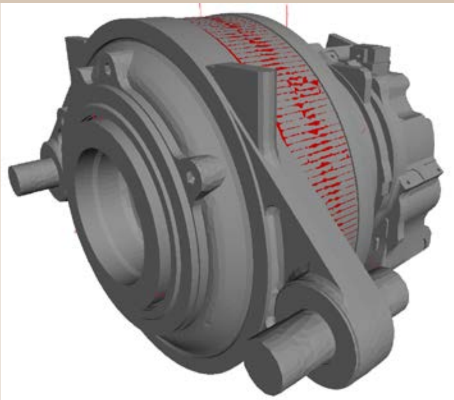
  6x6 stiffness matrix

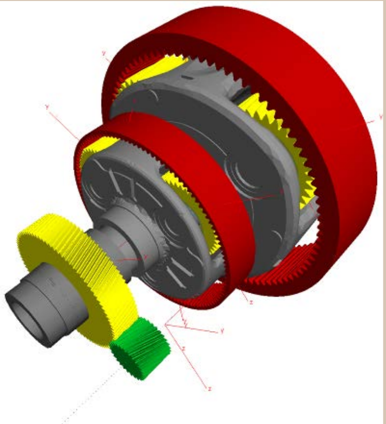
- Flexible components via CMS reduction:

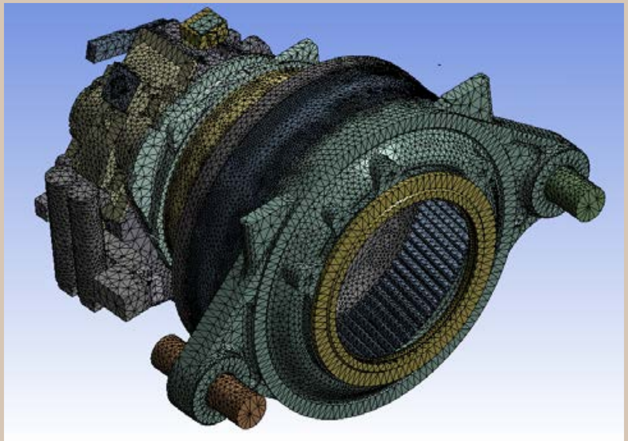
  - planet carriers

  - shafts

  - housing: mesh size 5cm,
  1st eigenmode < 100Hz, 1006 DOFs



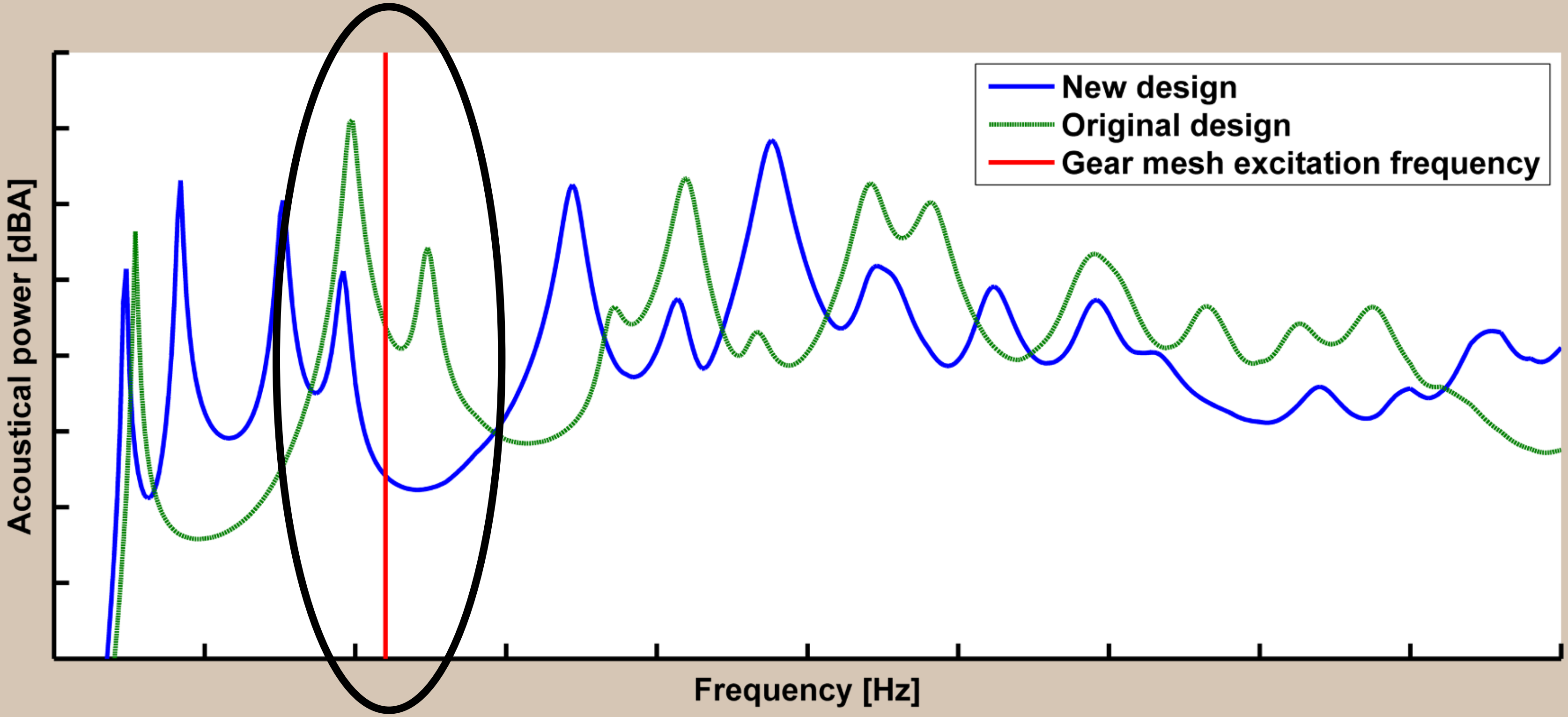




Gearbox design for low noise and vibrations

2. Transfer path optimisation: structure borne and airborne

Example of a housing design optimisation to avoid resonance



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Research project ALARM

“First time right” wind turbine design requires cooperation between stakeholders

Cooperation between 3 stakeholders in source and transfer path:

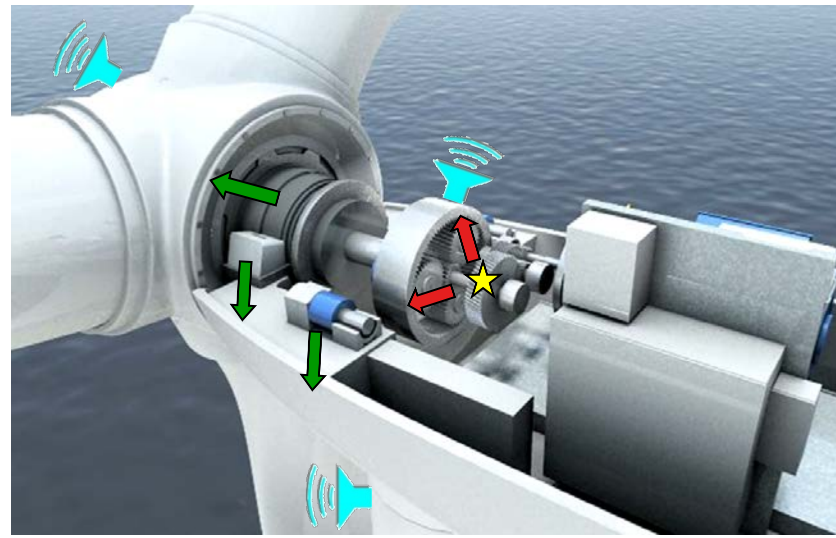
REpower Systems	WT manufacturer	Hamburg
ZF	WT gearbox manufacturer	Antwerp
ESM	Bushing manufacturer	Rimbach

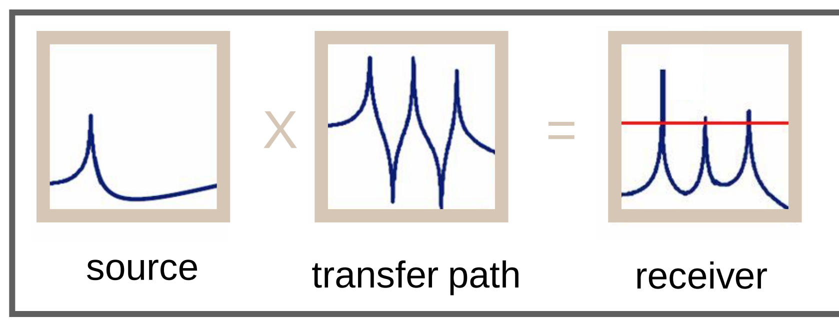
+ 2 engineering companies

Novicos	Software / Simulation	Hamburg
LMS Engineering Innovation	Software & Hardware / Simulation & Test	Leuven

+ 2 universities

KT mfk	Chair of Eng. Design	Erlangen
Katholieke Universiteit Leuven	Dept. Mechanical Eng.	Leuven



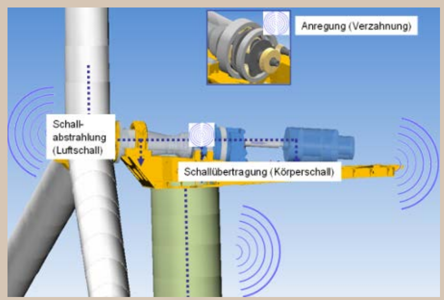


Research project ALARM

„Assistenzsystem zur Lärmreduzierten Auslegung Rotierender Maschinen"

Goal: Save money and time in the development of wind turbines, gearboxes and elastomer bushings by avoiding tonal noise issues in the field

Concept → Detail → Validation → ~~Troubleshooting~~



Total budget: German partners: 2.0 M€ ; Belgian partners: 1.8 M€ } with governmental support ~ high level of innovation

Duration: 3 years (01.03.2012 – 28.02.2015)

Research project ALARM

ALARM research activities

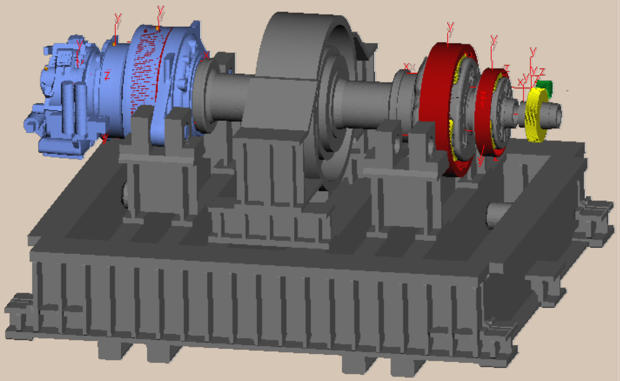
Simulations & Measurements

Data acquisition

KT mfk	Test rig measurements → Gear mesh excitation
ZF	WT measurement (a.o. TPA) → structure and airborne radiation
REpower Systems	Measurements: WT, high freq shaker → uncoupling structure borne transfer
ESM	Simulation WT → structure and airborne radiation
Novicos	Simulation test rig → Gear mesh excitation
Katholieke Universiteit Leuven	Measurements test rig, WT → Gear modelling, TPA

Research project ALARM

Repower 3.2M114 wind turbine



Status

ZF gearbox

- gearbox simulation models ready
- 1st proto gearbox test rig measurements done
- gearbox assembly in wind turbine planned

Outlook (planned for 2013)

- additional test rig measurements
- elaborate field measurement campaign
- correlation of simulations with experimental results

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Conclusions

1. Mechanical noise of wind turbines
   - ⇒ lower in overall sound power level compared to aerodynamic noise
   - ⇒ typically tonal and mainly structure borne noise
   - ⇒ avoid annoyance (= tonality) by reducing source level and optimising transfer path
2. Gearbox design for low noise and vibrations
   - ⇒ excitation reduction by optimising macro and microgeometry
   - ⇒ transfer path optimisation by using MBS and acoustic FE to predict the response
   - ⇒ additional analysis at wind turbine level enhances optimisation potential at gearbox level
3. Research project ALARM
   - ⇒ 7 industrial partners cooperating on ‘expert design system’ to avoid tonality issues in the field
   - ⇒ focus on Repower 3.2M114 wind turbine development:
     - ⇒ simulation of noise sources, transfer paths and radiation
     - ⇒ experimental analyses on test rigs and in the field to build up know how and verify models

Thank you very much for your attention!

Measuring wind turbine gearboxes

Suggestion for an efficient measurement strategy for WT gearboxes

1. Wind turbine should comply with (local) acoustic regulations

Measurements in prototype phase

↓

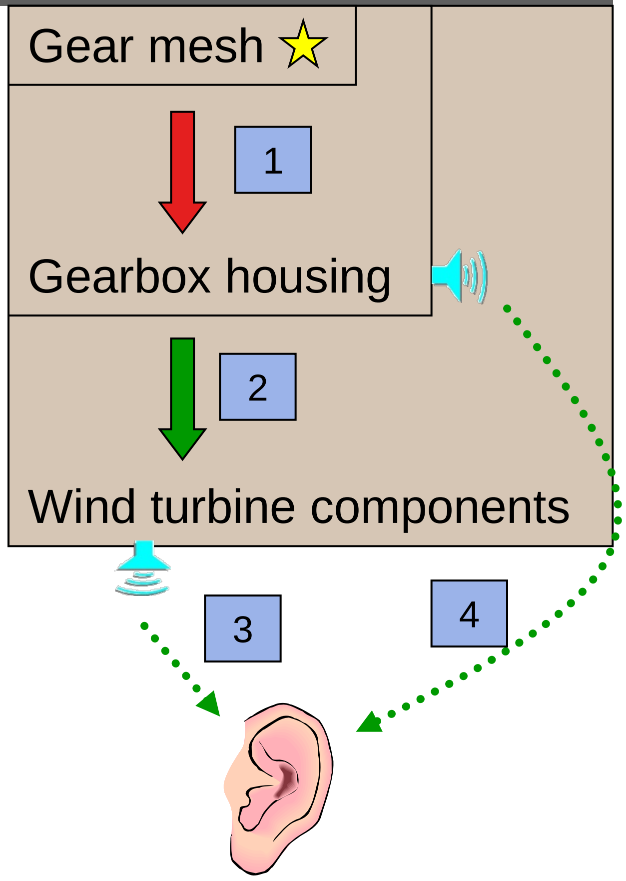
Correlation between test rig and in-the-field

2. Gearbox should meet general quality requirements

Test rig measurements in serial production

↓

Identify quality deviations



References

[1] Dr. Benoit Petitjean, Dr. Roger Drobietz, Dr. Kevin Kinzie, **Wind Turbine Blade Noise Mitigation Technologies,** in *Fourth International Meeting on Wind Turbine Noise,Rome Italy 12-14 April 2011*

[2] Rakesh C. Ramachandran, Hirenkumar Patel and Ganesh Raman, **Localization of wind turbine noise sources using a compact microphone array with advanced beamforming algorithms**, in Berlin Beamforming Conference 2012

[3] IEC61400-11 Ed.3: **Wind turbines - Part 11: Acoustic noise measurement techniques**

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