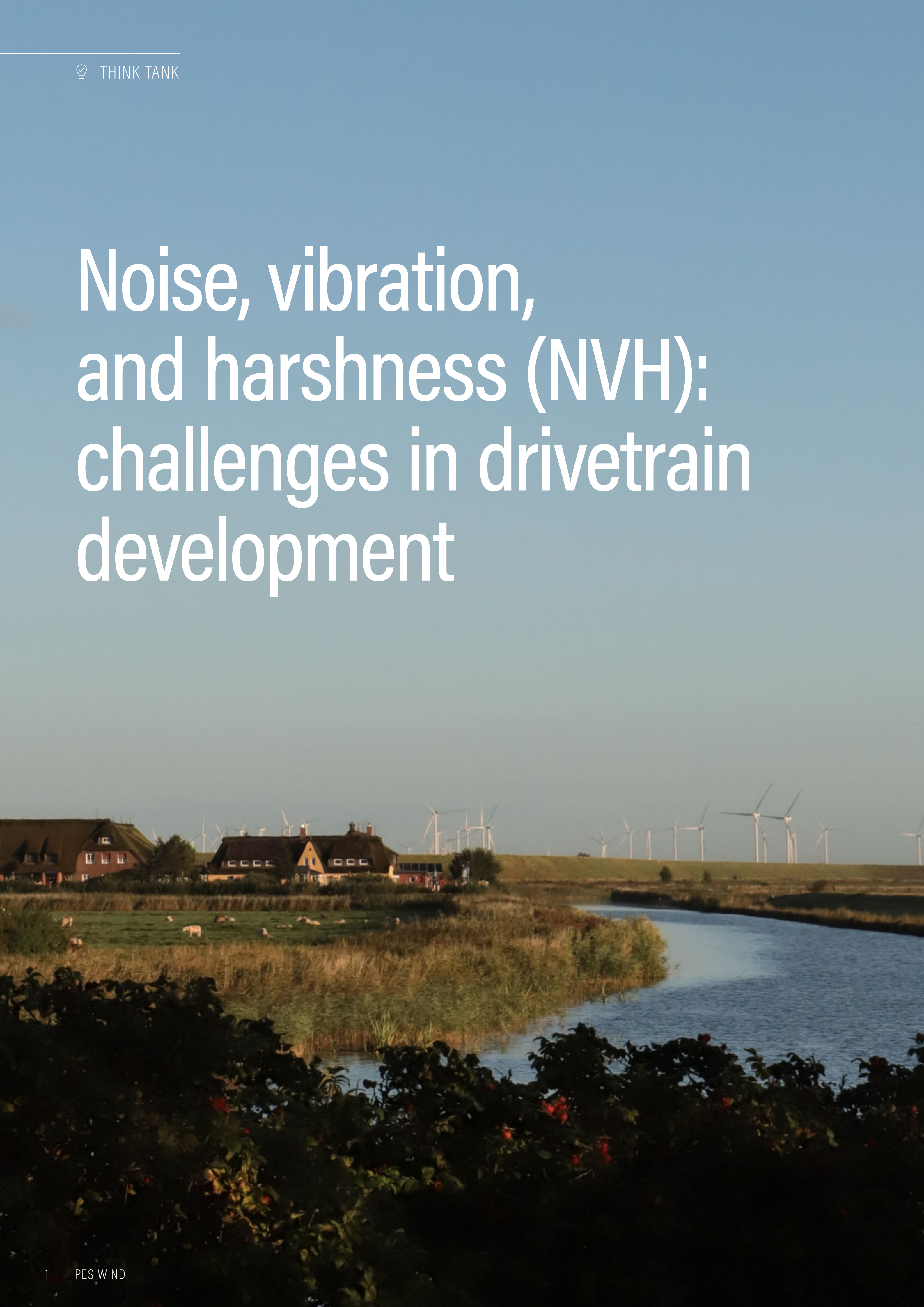
Noise, vibration, and harshness (NVH): challenges in drivetrain development



As onshore wind turbines are installed closer to urbanised areas and in ever-increasing numbers, wind turbine original equipment manufacturers (OEMs) are faced with increasingly stringent noise regulations. To date, this situation has been mostly restricted to the European continent, but other regions in the world are starting to follow this trend very rapidly. Turbine and gearbox manufacturers anticipate this movement and at supplier level, ZF Wind Power has developed an integrated simulation model to cope with these NVH challenges.

Tonality in the wind market

Wind turbine noise can be categorised in several ways, including total Sound Pressure Level (SPL) caused by aeroacoustic sound emissions of wind turbine rotor blades. Tonality can be caused by mechanical noise originating from specific wind turbine components like the generator, gears, cooling fans, bearings, etc. Tonal noise does not drive the total SPL of the wind turbine, but can still be perceived as annoying and therefore needs to be kept within strict limits. A tonality occurs when a tone stands out from the background noise, which, in the case of a wind turbine, is generated by the aeroacoustic emissions of the rotor blades.

Tonal noise can be classified as either structure-borne sound or airborne radiated sound. In the case of structure-borne sound, vibrations are generated at the gears/generator/cooling fans/bearings and propagated throughout the wind turbine drivetrain and wind turbine components and finally acoustically radiated by the wind turbine in the rotor, tower and nacelle.

In the case of airborne radiated sound, vibrations are generated at the gears/generator and are directly acoustically radiated by the gearbox housing/generator housing.

Challenges at different levels

A limit on the total SPL of wind farms translates directly into an economic impact on acoustics. The number of wind turbines that can be installed on a wind farm is in direct relation to the acoustic emission of each turbine. The lower the total SPL of each wind turbine, the more turbines can be installed. This has led to a trend in the wind industry to lower the aeroacoustic noise emissions of rotor blades.

Meanwhile, significant reductions of up to -10 dB have been achieved with the introduction of serrations, vortex generators, dedicated airfoil designs, and adaptation of the wind turbine controller. Unfortunately, decreasing the aeroacoustic sound emission of a wind turbine has a direct impact on the increased tonality level, as the background noise originating from the aeroacoustic emissions of the rotor blades has been lowered.

This is similar to the situation with Battery Electric Vehicles (BEVs), where the background noise, which used to originate from the combustion engine, has been reduced significantly with the introduction of the electrical engine. Therefore, NVH engineers in the automotive industry need to address undesirable mechanical noise in BEVs, which used to be blocked by the noise of a thermal engine in the past.

A lot of the tonality noise issues encountered in the wind turbine are of the structure-borne type. This means that the noise needs to be addressed at the system level: considering the design of a gearbox only will not reveal all potential noise issues that result in specific challenges in the cooperation between suppliers and wind turbine OEMs.

In addition to compliance with acoustic regulations, gearbox and drivetrain suppliers are faced with many other challenges. These include torque density increase measures, drastically increased power and torque levels of onshore wind turbines, and shorter design cycles. Moreover, gearbox and powertrain designs need to fit within so-called product platforms.

This translates into the need for NVH solutions that must be effective throughout the entire product platform as well as on both the supplier and OEM sides. The ZF platform, where gearboxes are designed for multiple customers; and the wind turbine OEM platform, where the gearbox/drivetrain needs to be vibroacoustically tailored to wind turbine platforms with multiple tower and rotor sizes.

What does ZF Wind Power do at the supplier level?

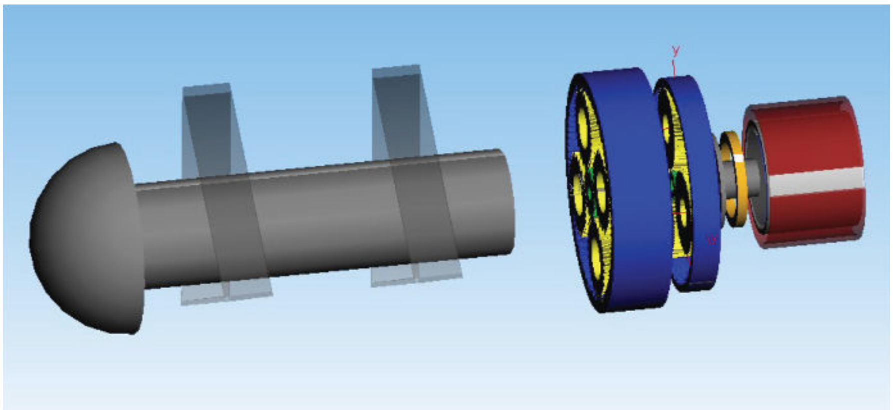
In the concept phase: an integrated simulation model

As a supplier, ZF needs to address the noise issues in the early stage of the gearbox or drivetrain design, where lots of design options are still open and the potential impact of a design change is still large: this is in the concept phase. The assessment of tonal noise requires a holistic simulation approach that considers all aspects of the problem, including the prediction of the tone line level, with an appropriate description of a source, transfer, and receiver model; and background noise, with an appropriate model of the different dependents.

The main problem is that software packages available on the market are not suited to perform NVH predictions in a concept phase when all design details are not available.

Therefore, ZF developed an integrated simulation platform that combines all the different aspects of the tonality level prediction. This simulation platform is linked to a library with fully parameterised, low-fidelity, drivetrain multi-body models.

This enables the evaluation of the NVH risks of different drivetrain configurations, as well



Parametrised wind turbine drivetrain model

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as different gear macro- and μ-geometry options. The cost impact of different design choices concerning NVH can be quantified using the integrated simulation platform, leading to a cost-optimal design that satisfies the NVH requirements. Furthermore, the simulation platform not only enables the selection of optimal design choices but also the full structural optimisation of the drivetrain using parameter sensitivity studies and design-of-experiment studies (DOEs), followed by surrogate modeling of the data and multi-parameter optimisation

Two examples of such a parameter sensitivity study are shown below on sun shaft stiffness and planet mass. The planet's mass varied between a full and a webbed planet design, whereas the mass in the latter was reduced to the maximum extent. The webbed planet design shows a 4 dB improvement compared to the full planet design.

A similar exercise was performed on the torsional stiffness of a sun shaft in the same Volume of Control where stiffness was varied between the minimum and maximum value. This graph indicates that the stiffer design has a 6 dB advantage compared to the most flexible design.

If the NVH assessment demonstrates a necessity, dedicated damper solutions are being developed to help solve specific NVH issues. The fact that damper design is already initiated in the concept phase enables sufficient time for preparation for the introduction into the serial product.

In the detailed design phase: upgrade to high-fidelity turbine models

In the detailed design phase, the low-fidelity models used in the conceptual design are further upgraded to high-fidelity wind turbine models, resulting in a full understanding of the wind turbine vibroacoustic behaviour concerning drivetrain dynamics. Potential problems overlooked in the concept phase can still be solved before the actual product validation.

In the validation phase: a more detailed sensory set-up in a test center and on-site

In the validation phase, the gearbox/drivetrain design is validated at a test set-up, enabling a more detailed sensory set-up compared to the field environment as well as the validation of the gearbox/drivetrain simulation models that have been included in specific test set-up models. Correlating the test set-up simulation models with the measurements allows for improved drivetrain models in the wind turbine.
In the final stage, the gearbox/drivetrain is validated in a field environment in the real wind turbine application, providing the final proof of the NVH quality of the design.

What's next?

The trend of including NVH in the gearbox/drivetrain design is here to stay and will become ever more important. Because the cost of optimising gearbox/drivetrain designs based on experiments in the wind turbine is extremely costly and does not allow fast product development cycles, simulation-driven design is the way to go.

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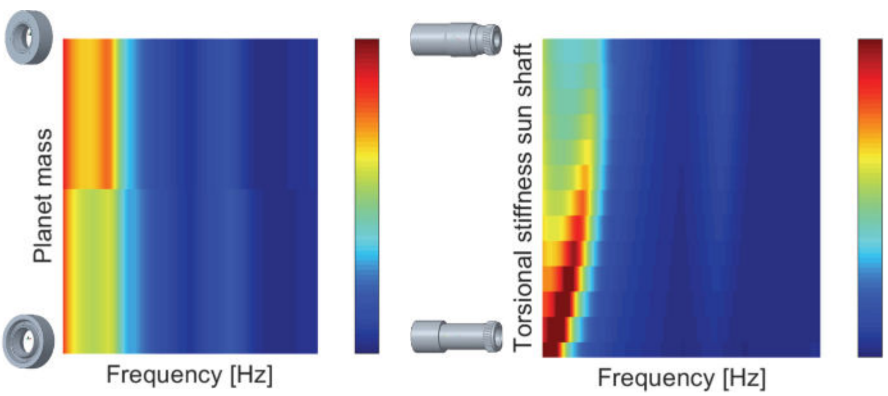

Sensitivity studies on planet mass and sun shaft stiffness

About the company

ZF Wind Power is a worldwide, leading, technology-driven manufacturer and service partner in the global wind turbine gearbox industry.

The company is leading the high-performance onshore segments with products of up to 8000 kNm and was the first to exceed 200 Nm/kg torque density in compact modular platform designs.

It delivered the world's first offshore 9.5 MW wind turbine gearbox and delivered, in close cooperation with its partner, the first 15 MW complete powertrains for the offshore market.

ZF has the largest global installed capacity of +8 MW offshore wind turbine gearboxes.

Since it entered the wind industry in 1979, ZF Wind Power has delivered more than 80,000 gearboxes, powering as much as 180 GW, mainly high-performance, wind turbines, covering almost 25% of the total installed capacity of gear-driven wind turbines worldwide.

Together with its partners, the company constantly invests in the wind market to empower a sustainable future.