Case study

ZF Wind Power

Improving the gear load carrying capacity and noise performance of wind turbine drivetrains: Using Romax Enduro in a simulation-led design process verified by physical correlation

"Romax Enduro is helping us to tackle the current challenges faced by the wind market. We are able to create a virtual representation of the gear system and the test environment. This means, firstly, that we can fine tune our micro geometry to achieve an optimized load distribution on the gear flank and in the gear root over a wide torque range, and, secondly, that we can detect noise risks early in the design process and identify design measures to mitigate those risks."

Nico De Bie,
Gears Excitation Engineer at ZF Wind Power

ZF Group have production, development, sales and service sites worldwide, with 271 locations and 153,000 employees in over 42 countries. They have divisions focusing on Mobility (eMobility, commercial vehicles, car chassis and powertrain, safety systems) and on Industrial Technology (aviation, marine, off-highway, mining, and wind power).

The Wind Power business unit is founded on some of the richest wind turbine driveline experience of the 20th century, combining ZF (founded in 1915), Hansen transmissions (active since 1923, acquired by ZF in 2011), and the large gearbox department from Bosch Rexroth Wind (started in 1920, acquired by ZF in 2015). Based on this strong background, ZF Wind's portfolio covers the total wind market, with products ranging from 2.xMW to 10.xMW, developed for both onshore and offshore applications. Much of the production process is in-house, from gear manufacturing to heat treatment, high precision machining of the castings, quality assurance, and test rig facilities (with a maximum testing capability of 13.2MW).

Client

ZF Wind Power, whose product portfolio covers the complete wind turbine market, and who currently have more than 143GW assets installed onshore and over 7GW installed offshore.

Challenge

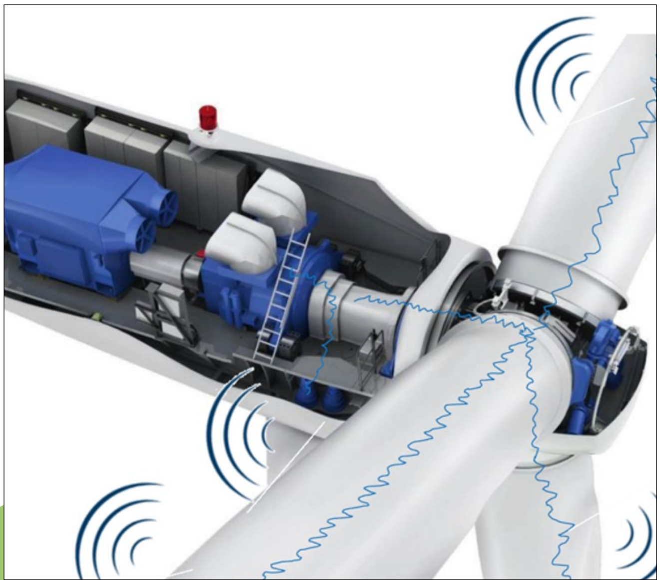
Developing power-dense, lightweight wind turbine drivetrains whilst minimising transmission error in order to avoid tonal powertrain noise.

Solution

Using Romax Enduro to create simulation models of the drivetrain including gear mesh simulations and measurements to optimise gear loading and transmission error.

Benefits

Reducing the cost of energy through increasing the power density and durability of wind turbine drivetrains; adopting a simulation-led development process to design drivetrains with low risk of transmission noise.



ZF Wind Power started using Romax software over 10 years ago, initially to simulate roller bearings within a flexible model to determine the optimum clearance settings for contact stress and life. Nico De Bie, Gears Excitation Engineer at ZF Wind Power, explains, “Although bearing calculations were our initial reason for using Romax software, we have more recently expanded our use of Romax Enduro to further explore gear modelling and design options at the drivetrain level, for example multiple planet systems, drivetrain dynamic behaviour, gear micro-geometry design, root stress analysis and estimating gear excitation.”

Reducing the cost of energy and minimising noise

As the wind turbine market grows to meet the demands of global sustainability initiatives, manufacturers are constantly pushing for higher power generation capacity at lower unit cost. To achieve this, significant steps have been made over the last decade regarding weight reduction and torque density increase, although there is still a great deal of work to be done. De Bie comments “The wind market is facing critical challenges. We are looking to reduce the cost of energy, in part by decreasing the amount of materials used and reducing the overall size of the turbine parts. Wind turbine OEMs are also looking to extend the potential wind areas, both by expanding their range in ‘high wind’ zones and by exploring new ‘low wind’ zones.”

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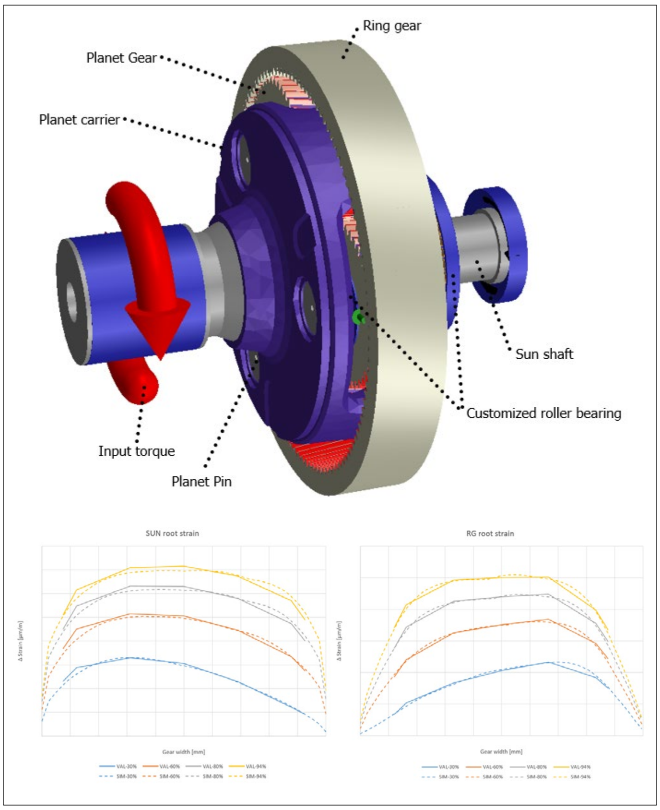
As zones increase and turbines shift closer to residential areas, low noise is critical in order to minimise disturbance. Since the largest portion of wind turbine noise is generated by the rotating blades, decreasing the sound is generally achieved by blade redesign and noise-reduced operating modes e.g. reducing rotor speed at night. However, it is not only the blades which emit noise. Vibrations from the gear unit or generator are transferred towards the turbine structure and can be emitted as noise via the blades, tower or nacelle. This mechanical noise is typically tonal in behaviour, meaning it stands out from that of the blades. As a result, manufacturers are under pressure to minimise gear excitations, aiming to achieve ‘tonal free’ wind turbines.

De Bie comments: “To face these challenges, we need to reduce the sound power level, and, critically, develop power dense, perhaps non-conventional designs, at smaller weight and delivering higher torque. Romax Enduro is a key part of helping us meet these demands.” In the following sections, ZF share several examples of how they use Romax Enduro to meet the demands of the wind industry.

Increasing gear load carrying capacity

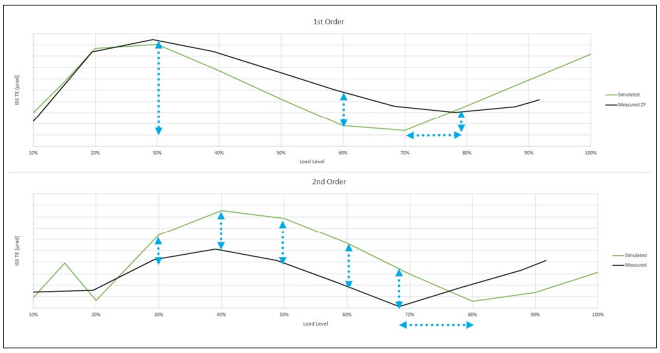
The first example is a conventional planetary gear stage design. ZF built a simple Romax model, with a grounded ring gear and no finite element (FE) housings, and compared the load patterns and root strain results from Romax Enduro with their measurements (see below). De Bie comments: “The Romax gear contact model results in realistic flank stress distributions considering system deflections, local component deformations and gear topologies under varying load conditions. There is very good correlation between our gear load measurement and simulation in Romax Enduro. Since Romax considers system load dependency, the mesh misalignment also matches the test rig value well. These results gave us confidence in the simulation model. Having this kind of simulation of the gear stage allows us to further optimise the gear topology definition.”



Top: Planetary gear stage design modelled in Romax Enduro; Bottom: Correlation of root strain values against mesh width of the sun (left) and ring (right) gears, showing measurement vs simulation at varying load levels

Using the Romax simulation, ZF were able to decrease the load distribution factors for this design significantly over the entire load range. This leads to improved load carrying capacity of the gear stage, which, as De Bie suggests, can have multiple benefits: “We have two options here. Either, we can decrease the total component width, i.e. reducing materials and cost, or we can expect the gear unit will be able to cope with higher load demands throughout the lifetime of the product.”

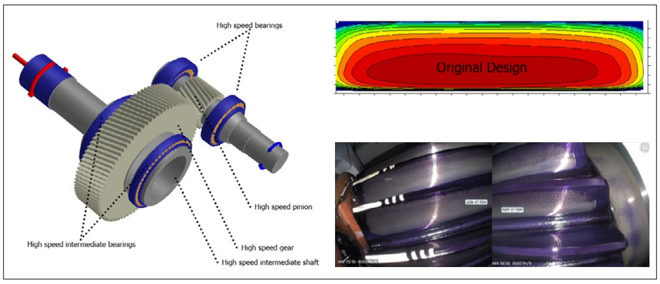
However, despite this improvement for durability, ZF still had challenges with the tonality, so used Romax Enduro’s Gearbox Transmission Error (TE) functionality to explore and mitigate the noise risk. The graph below shows correlation of measured TE with the Romax simulation. “The TE correlation shows a good match in both shape and amplitude,” De Bie comments. “This is especially impressive considering the model is hugely simplified. To save time, we do not account for gravity in the simulation – this means we only need to calculate a single tooth pass, rather than an entire planetary rotation. Additionally, we were using an ideal topology, not accounting for production deviations, and only modelled a single gear stage. Our test rig set-up also has imperfections – we are doing back-to-back testing, there are vibrations in the environment, we have limitations regarding the sensor positioning, stiffness of the sensor brackets, the accuracy of the sensor, and the speed and torque conditions. In light of these simplifications in our modelling and imperfections in our test rig, the TE correlation is remarkable. The results are so close that we can use them to inform our design process.”



TE results: simulation vs test rig (1st and 2nd order plots)

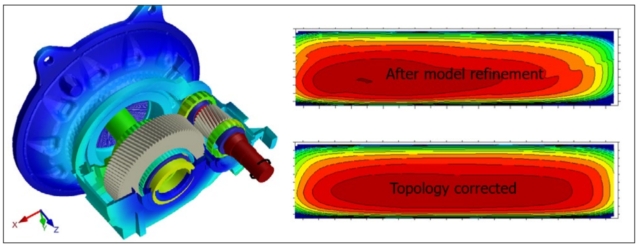
Finding the right level of model complexity

The second example is a parallel gear stage design. ZF started off by building a very simple Romax model, where simulation results showed a centralised contact pattern on the gears. However, on the test rig, the results were different, with the prototypes showing uneven loading - higher on the left-hand side of the gear. It was unclear at the time whether this was caused by incorrect misalignment, deviations between simulation and measurement, or insufficient time on the test rig, resulting in the paint not indicating the wear correctly.



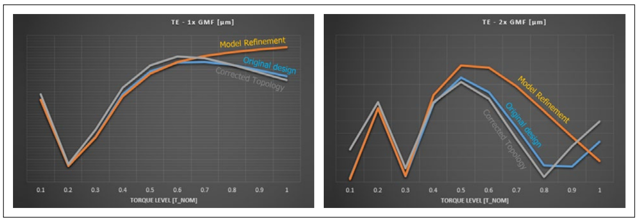
Although the very simple Romax model (left) showed a central contact pattern (top right), the test rig showed more loading on the left side of the gear than the right (bottom right)

Some additional root strain measurements confirmed the uneven loading, so ZF returned to the Romax model and added more complexity: an FE housing, connections from the outer bearing rings to the FE housing, and set the correct bearing clearances used during testing. This refined simulation model then showed the same uneven loading pattern. Once satisfied with the correlation, ZF could then adjust the simulation model to test out potential design improvements to centralise the contact pattern.



The more complex Romax model with FE housing (left), contact pattern after refinement matching the test rig results (top right), contact pattern after further optimisation (bottom right)

De Bie explains: “Our aim is to have the simplest model to achieve correlation. In this example, we defined the topology based on a very simple model with no housing. However, this did not match what we were seeing on our test rig. So we refined the model until we saw correlation. Once that was achieved, we could use this model to make changes to the micro geometry to centralise the load pattern in simulation, with confidence we would see the same results on the test rig. With this more detailed simulation model, we were also able to obtain more accurate TE results, and subsequently we reduced the risk of noise issues in this design.”



The original simple simulation model (blue) showed decreasing TE above 50-60% torque but the test rig actually showed an increase. After refinement, the simulation model (orange) matched this observation, and some further optimisation of the more complex model improved the TE (grey). Left – first order harmonic, right – second order harmonic

Achieving a simulation-led design process

Although ZF Wind have been using Romax software for many years, it has taken time for the capability to be widely accepted as a core part of the drivetrain development process, as De Bie explains, “Initially, we had some work to do to persuade our technical teams about the capabilities. Thanks to the support from the Romax team, we achieved a better understanding of the right modelling approach. We have improved the way in which we use Romax software and the processes which we have in place. We now see Romax as a state-of-the-art tool for advanced gear mesh analysis.”

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Stephen Smith, Head of Business Development for System Dynamics at Hexagon, comments on the relationship with ZF Wind: “There was always a common goal between ZF and Romax. Together, we have worked hard to create the right environment for ZF to meet wind turbine challenges, subsequently furthering our joint agenda in sustainability.”

De Bie concludes: “Romax Enduro is helping us to tackle the current challenges faced by the wind market. We are able to create a virtual representation of the gear system and the test environment. This means, firstly, that we can fine tune our micro geometry to achieve an optimized load distribution on the gear flank and in the gear root over a wide torque range, and, secondly, that we can detect noise risks early in the design process and identify design measures to mitigate those risks.”

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Our technologies are shaping urban and production ecosystems to become increasingly connected and autonomous – ensuring a scalable, sustainable future.

Romax, part of Hexagon’s Manufacturing Intelligence division, provides world-leading solutions for the design, analysis, testing and manufacture of gearboxes, drivetrains and bearings. Learn more at romaxtech.com. Hexagon’s Manufacturing Intelligence division provides solutions that utilise data from design and engineering, production and metrology to make manufacturing smarter.

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