Leading wind turbine gearbox technology in noise reduction

PES is delighted to bring you this latest advanced technology solution from ZF Wind Power. Over the last few years total wind turbine noise, which is mainly generated by the interaction of the wind and the wind turbine structure, has changed from being one of the properties of a wind turbine to a true differentiator between different wind turbine OEMs: the less noise the wind turbine generates, the more wind turbines can be placed on the same piece of land without violating the prevailing noise regulations.

To achieve this, wind turbine OEMs are investigating among other things reducing overall noise levels by utilising optimised low noise blade design using e.g. serrations and improving controller strategies to include a wide variety of low noise modes.

As the overall wind turbine noise is used to mask the noise coming from the mechanical components inside a wind turbine such as the generator and the gearbox, these noise sources also need to be optimised. The low noise blade designs, which are still being studied, have a direct impact on the overall wind turbine noise and thus require the mechanical noise to be reduced at the same pace. Next to that, the increased number of low noise modes, which typically just reduce operating speed while maintaining normal torque, widen the overall operating envelope.

As a consequence of this, the overall wind turbine noise, which is mainly linked to the rotor speed, reduces significantly. By doing so the mechanical noise also needs to be optimised further. Mechanical noises originating from the drivetrain in conditions such as nominal torque and nominal operating speed, which were previously completely masked by overall wind turbine noise, now are not masked anymore by the overall wind turbine noise due to this reduced operating speed.

ZF Tonal Free Wind Turbine process

To reduce the mechanical noise originating from the gearbox, ZF Wind Power has worked out an integrated approach. This approach, called the ZF Tonal Free Wind Turbine process, is aligned with every step

of the design process to guide the design towards an optimised low noise gearbox. It consists of 4 main sub-processes and has a main goal to identify, track and mitigate potential tonalities, called risks, throughout the complete drive train design.

During the first sub-process, called concept optimisation, all potential macro geometry candidates are evaluated with respect to gear excitation levels and potential tonalities caused by large torsional resonances occurring inside the defined wind turbine operating range. The main goal here is to reduce the overall excitation level and to try to shift as many global torsional resonances out of the operating range as possible. Torsional resonances still in the operating range are considered further on as tonality risks, are tracked and depending on their severity mitigated in this or in the next process step. Final selection of the resulting macro geometry from all potential macro geometry candidates is based on this assessment and other selection criteria such as rating and cost.

The next process step focusses on the detailed design. More complex models are used to re-evaluate the identified torsional risks and to detect new non-torsional risks such as bending modes.

Figure 1 shows such a complex model which typically contains the drive train: main shaft, gearbox, generator, main bearing; as well as the main frame, the tower and the rotor assembly; all of them modelled as flexible components. Next to that, also nonlinear bearings, nonlinear gear forces, generator and wind loadings are included to try to represent the dynamic wind turbine behaviour as good as possible.

Using this model, sensitivity studies are executed and mitigation strategies, such as shifting modes to a more insensitive operating region or reducing gear excitation, are sought to mitigate those risks. Depending on the collaboration model between wind turbine OEM and ZF, ZF can model the complete wind turbine including the drive train or this effort is shared between both partners.

The main challenge here is to have this model, the sensitivity studies, the mitigation strategies and the solutions for each risk available before the so-called design freeze where nothing can be changed to the design anymore. In this process step, besides optimising the design, the gear microgeometry is also optimised. Using microgeometry modifications in many cases it is unfortunately not possible to reduce the gear excitation over the complete operating range, and the actual risks are used to identify the regions in the operating range for which the gear excitation should be optimised and regions increasing gear excitation will not impact the overall noise behaviour.

In contrast with optimising blades to reduce noise, which can be done solely by the blade manufacturer, or by introducing new low noise modes which can be done solely by the wind turbine OEM, optimising the mechanical drive train cannot be done by the drive train OEM alone. Close cooperation with the wind turbine OEM is crucial to reach the ultimate goal. Main reason for this is that the drive train is integrated strongly in the wind turbine structure resulting in a strong coupling between the drive train and the wind turbine structure requiring an overall optimisation of both drive train and wind turbine structure.

During the complete tonal free wind turbine process and the detailed design process step in particular it is crucial that both the wind turbine OEM and the drive train or gearbox OEM share highly confidential information and models or even team up to jointly perform the required computations, modelling and simulations. This results in

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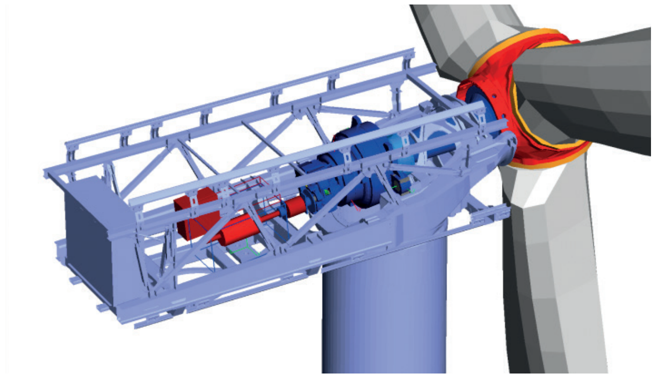

Figure 1 - Detailed dynamic model of a wind turbine

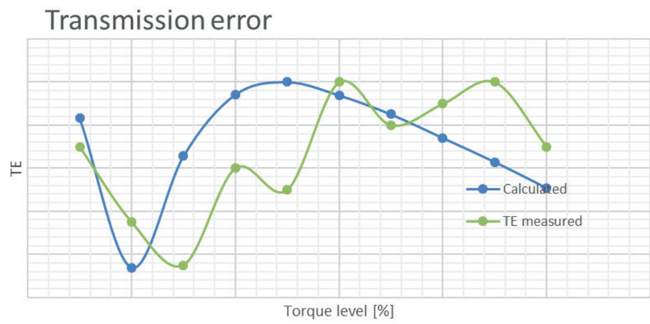

Figure 2 - Transmission error of an individual gear pair: simulated and measured inside a complete gearbox

by far the best output as then both OEMs can share knowledge and insight to optimise the drive train to its fullest extent.

In the third step, measurements are performed to validate the model and more importantly to validate the chosen mitigation strategies. These measurements typically take place on the end-of-line test rig and are highly focussed on the identified risks. This approach is only indicative and mainly focusses on validating the mitigation strategies as unfortunately the measurement results cannot be used to assess the drive train behaviour in an absolute way.

Although noise and vibrations can (and are) measured on this end-of-line test rig, they do not provide full insight in the resulting noise behaviour when the gearbox will be mounted in the turbine: it is unclear how the noise produced by the gearbox directly (= airborne noise) will be masked by the overall wind turbine noise, how the vibrations will be transferred to the tower and the blades (= structure-born noise) and radiate from those surfaces which are more efficient noise radiators than the gearbox itself, and how the different surroundings end-of-line test rig versus wind turbine will affect the measured noise and vibration behaviour.

For this reason a comprehensive field assessment focussing on one or preferably on more than one wind turbine is still required. During this last process step the main goal to achieve is to verify that indeed no mechanical noise is perceptible in any operating condition of the tested wind turbine(s).

This integrated process approach allows ZF Wind Power to use all the current state of the art knowledge and simulation techniques to optimise the drive train noise behaviour. As it is in the wind turbine OEM's interest to continue optimising and reducing wind turbine noise behaviour, ZF Wind Power follows this approach and keeps investigating in research and development in this area to maintain pace with the wind turbine OEM. Recently an important technological step was taken: performing a transmission error measurement on a complete wind turbine gearbox. Transmission error is considered as the main source of noise of meshing gears. It is defined as the instantaneous rotational fluctuation of a gear, expressed in radians or a linear deflection along the line of action, if its counter gear were to be rotating at an exact constant speed.

Although transmission error is being evaluated and optimised throughout the tonal free wind turbine process, being able to measure transmission error is an important improvement as the transmission error of a wind turbine gearbox is in the region of 0.1 to 2 μm and is heavily dependent on the microgeometry of both gears, their alignment, shaft, housing and bearing deflections, etc., making validation of these calculations crucial. Figure 2: shows the results of such a measurement in green and compares it with a simulation of that specific stage inside the gearbox.

As can be seen further improvements can be made, probably both on simulation and measurement side, but the main characteristics such as the pronounced dip and the increase and decline afterwards are already in line. With this new measurement technique ZF Wind Power is capable of validating and further fine-tuning its microgeometry optimisation approach.

By applying the combination of implementing all knowledge during the design process, using the tonal free wind turbine process and by further investing in noise and vibration related research and development, ZF Wind Power is convinced that, together with the wind turbine OEMs, it can solve today's mechanical noise issues and will be capable of solving the mechanical noise issues of tomorrow.

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ZF Wind Power is a globally established designer, manufacturer and supplier of reliable and advanced gearbox solutions for multi-MW wind turbines with power capacities ranging up to 9.5MW.