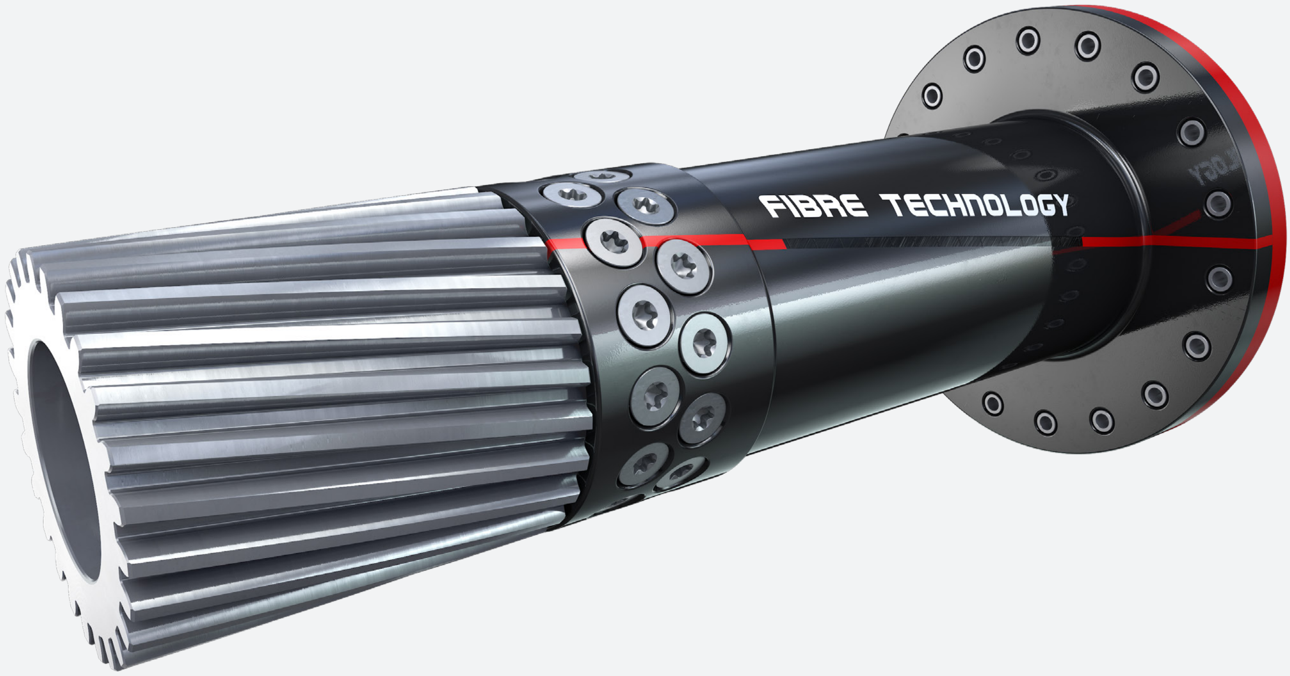


Tackling noise, efficiency, and reliability in wind turbines

A shift towards more integrated drivetrain architectures in wind turbines is being driven by the need to boost power density, resulting in increased challenges with noise, vibration, harshness, and tonality. Geislinger's advanced solutions are proving effective in mitigating these issues, enhancing turbine robustness and reliability.

A clear trend towards more integrated drivetrain architectures is emerging across all markets, primarily driven by the need to increase the power density of wind turbine drivetrains. Typically, a rigid arrangement consisting of a main bearing unit, gearbox, and generator lacks elastic elements, such as flexible gearbox mounts or high speed shaft couplings. As a result, residual non-torque loads are transferred directly to the gearbox, causing unfavorable parasitic forces.

This reduced decoupling of components can also introduce new challenges related to the NVH (noise, vibration, harshness) behavior of wind turbines, as vibration sources like the gearbox and generator can no longer be isolated in terms of loads and structure-borne sound. This inevitably leads to tonalities that must be managed before they reach the sound-radiating surfaces of the tower and blades.

Additionally, continuous advances in aerodynamic noise reduction are leading to less masking of drivetrain sounds. Increasing power densities also affect the dynamic behavior of the system due to the higher ratio of excitation energy to the damping effect of the drivetrain mass.

Coupled with stricter noise regulations and the necessity of constructing wind farms closer to urban areas, it is evident that tonalities are becoming a focal point in the wind industry. Tonality directly impacts the costs and the annual energy production (AEP) of wind turbines.

Operating at low wind speeds, especially in urban areas, can lead to tonality penalties and even complete energy production shutdowns. Even the use of advanced smart controls to reduce noise and tonality can result in a 2 to 4% reduction in AEP for every decibel.

Parasitic drivetrain loads and tonality

Tonalities can be efficiently neutralized by systematically decoupling excitations in the drivetrain from the sound-emitting surfaces of the wind turbine. A low speed shaft coupling (LSSC) made of advanced composites has already proven effective in reducing gearbox input loads in offshore wind turbines, thereby enhancing their robustness and reliability.

Wind turbine manufacturers must also consider that failures are not just rare occurrences but often result from designs that are not robust, aimed at reducing costs and increasing perceived competitiveness.

A semi-integrated drivetrain architecture with an LSSC that absorbs over 90% of parasitic forces significantly improves the reliability of both the powertrain and the overall wind turbine. While this approach may slightly increase the initial capital expenditure (CAPEX) of the turbine, it ultimately saves money by avoiding costly gearbox replacements and reducing downtime over the years.

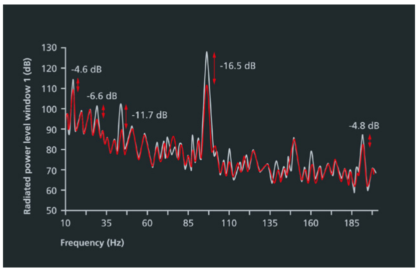
There are numerous publications on the effects of a low speed shaft coupling (LSSC) on reducing gearbox loads and increasing turbine robustness and reliability. However, a new question arises: to what extent does such a powertrain element limit the transfer of structure-borne sounds into the noise-radiating components of wind turbines, specifically the tower and blades?

To address this question, Geislinger collaborated with the Center for Wind Power Drives at RWTH Aachen. They set up a 6 MW medium speed wind turbine model in a multibody simulation (MBS) environment. The study compared a reference model, representing the latest medium speed architecture of a fully integrated, directly coupled powertrain, to an advanced model featuring an LSSC between the main shaft and gearbox input shaft with a pivoted planet carrier.

To quantify the effect of the LSSC on tonality mitigation, transient simulations, and dynamic analyses were conducted. These included a transfer path analysis and the calculation of radiated sound power from the main noise-emitting surfaces, the tower and the blades.

The effect of a low-speed shaft coupling on tonality

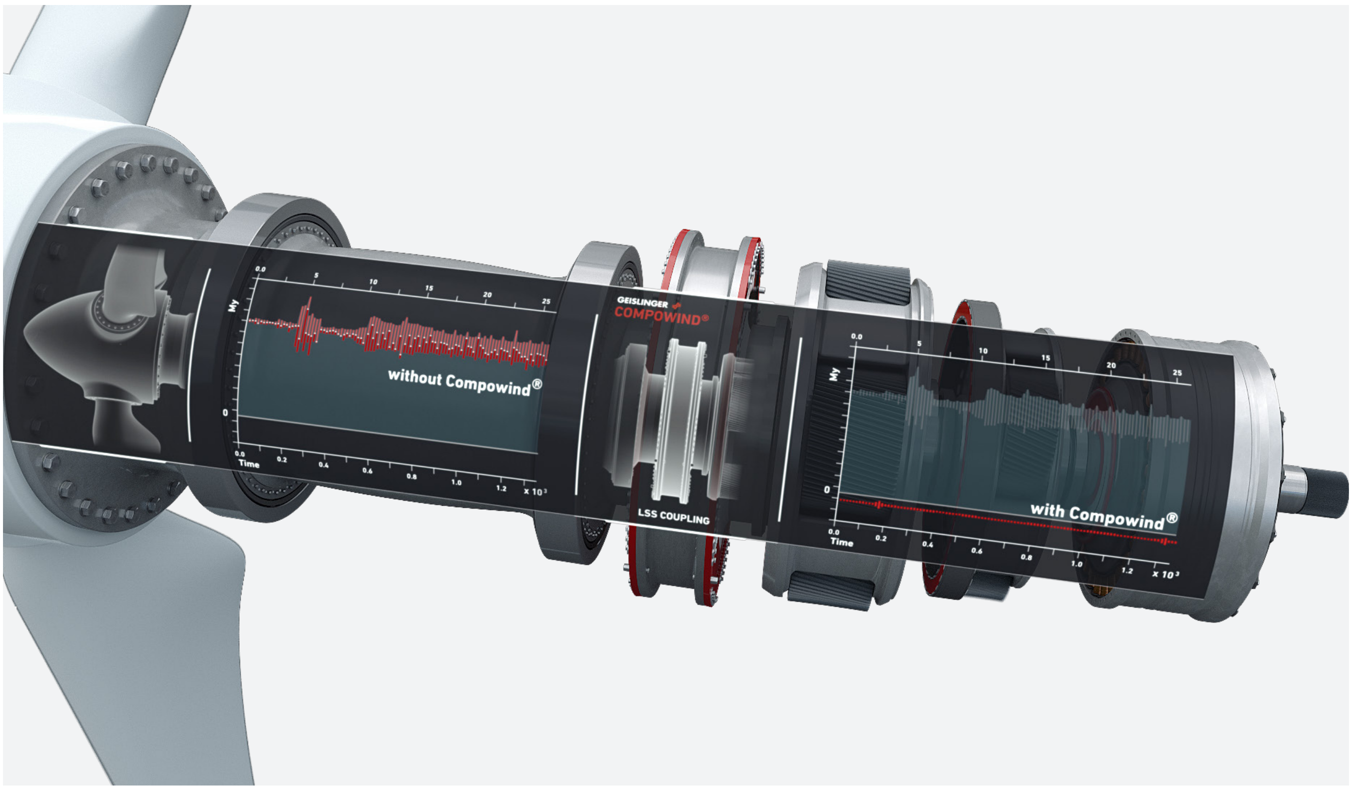
Comparing blade accelerations reveals a significant influence on dynamic behavior. The advanced model, featuring the coupling and planet carrier bearings, represented by the red graph, reduces blade root and blade tip accelerations by 70 to 85% compared to the direct coupled reference model, represented by the black graph.



Calculations of the radiated sound power from the rotor blades show a reduction of up to 16.5 decibels. Although these are simulation results and not microphone measurements under real world conditions, they provide valuable insights into the potential of an LSS composite coupling to eliminate tonalities.

The comparison of tower top acceleration shows an impressive amplitude reduction of 40 to 70%, resulting in a reduction in total sound power radiated from the tower of up to 15 decibels. This is a particularly interesting outcome of the simulation work, as it was initially anticipated that the coupling would only affect the sound path from the gearbox shaft to the main shaft and subsequently to the rotor blades.

However, the results demonstrate that a significant portion of the sound travels from the main shaft through the bearings and the main bearing unit back to the main frame and the tower.



Less that 90% load reduction, compared to elastomer-hydraulic torque supports

Root cause mitigating with a torsional damper

Another approach is to address the origin of drivetrain sounds, particularly mode shapes in the frequency range up to 250 Hertz. One of these is the torsional eigenfrequency, dominated by the second planetary stage of typical two- or three-stage high and medium speed wind turbine gearboxes. The meshing of the second stage causes angular accelerations and torsional vibrations, putting the entire gear stage into resonance with the stationary gearbox parts. If this resonance frequency matches a drivetrain eigenmode, which is common in many gearbox designs, the result is the formation of audible, annoying sound, or tonality.

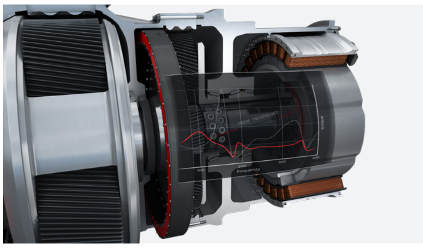
A torsional damper at the planet carrier, tuned to the main excitation frequency, can effectively absorb angular accelerations, thereby mitigating tonality-relevant vibrations. This damper has been in serial use as an effective solution for reducing tonality. Validations at the gearbox and nacelle systems levels, as well as microphone measurements taken in the field, have confirmed its promising simulation results.

Silentshaft®: a powertrain solution made of advanced composites

The Silentshaft® is a composite driveshaft based on the Geislinger Gesilco® product family, similar to the Compowind® low speed shaft coupling, and serves as a direct replacement for a standard steel sun shaft.

Due to its exceptional physical properties, it significantly reduces torsional stiffness compared to a steel shaft. Industry experts recognize the impact of reducing the torsional stiffness of the output sun shaft in the last planetary stage of the main gearbox, as typical eigenmodes are often influenced by this stiffness. A steel sun shaft imposes hard limits on desired stiffness reductions.

By introducing a semi-torsional elastic coupling using advanced composites, the range for tuning torsional stiffness can be expanded. A notable advantage of a carbon fiber sun shaft is its seamless integration into co-axial gearboxes, eliminating the need for an 'add-on' product.



The first generation of this new technology has been successfully tested and validated at both the component and system levels, as well as in the field through microphone measurements. Geislinger is currently collaborating with major industry players to further develop this technology to achieve full maturity. The clear goal is to use it as a universal solution for eliminating tonality across all platforms, following successful validation.

Outlook

A significant milestone was achieved when a major European wind turbine OEM chose a semi-integrated medium speed architecture with the Compowind® low speed shaft coupling (LSSC) for its next-generation onshore turbine. This decision marked a key step toward developing a robust and tonality-compliant turbine.

The composite sun shaft, Silentshaft®, is now in its third generation. The latest design modifications aim to further reduce torsional stiffness while adhering to a strict design envelope. This advancement is the result of a thorough, multi-year development and validation program, including field tests with a number of Silentshafts®. The goal is to establish this technology as a standard solution for tonality mitigation on both new and existing platforms.

Additionally, Geislinger is applying technology from other applications to develop the Geislinger Hub. Originally designed to reduce weight and inertia in high speed ferry shafting arrangements, this hub features an in-house developed friction coefficient increasing technology.

A composite sleeve, which absorbs most of the hoop stresses from the shaft-hub coupling, offers an option for further weight reduction. Unlike traditional coatings with diamond-like particles, which are banned for rotor shaft hub couplings due to their impact on hard shaft materials, the Geislinger friction increaser provides an appealing alternative for wind turbine drives. Further weight reduction through advanced composites could help meet road transportation and crane payload limitations for future large onshore wind turbines.

Finally, Geislinger is exploring the development of a gearbox-integrated LSSC to transform cost-effective three-point support architectures for high-speed powertrains.

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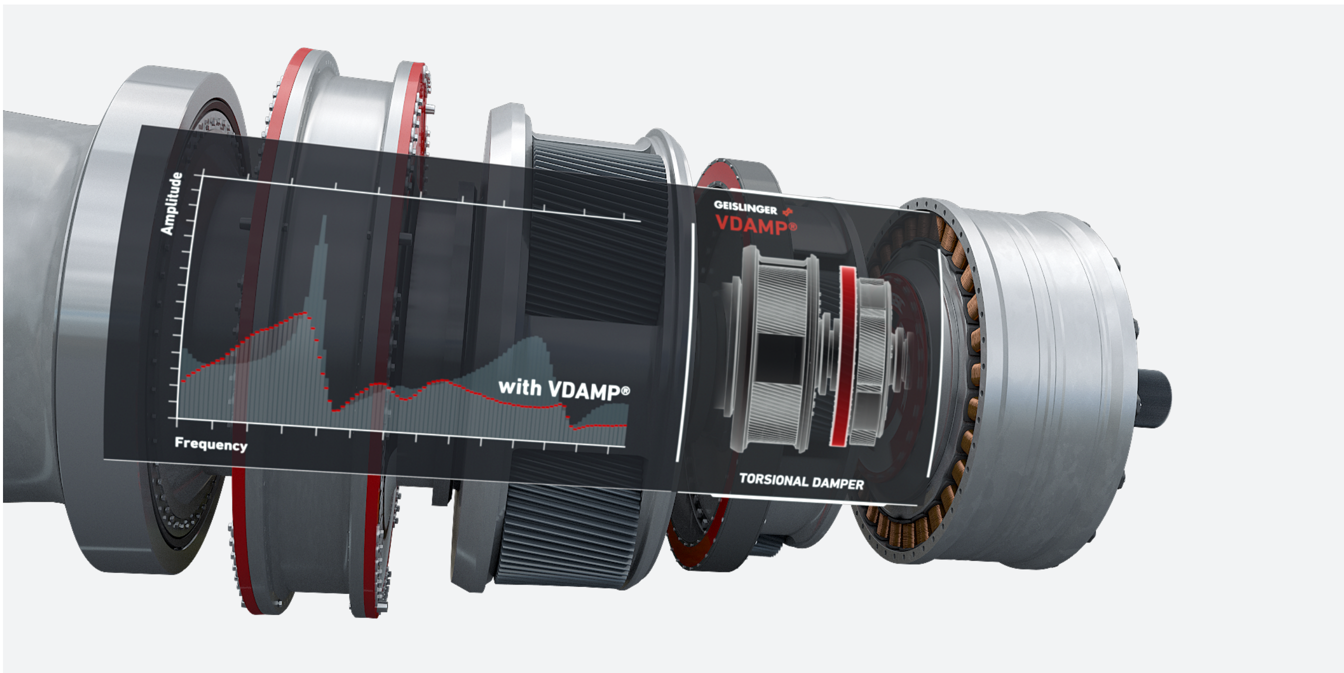

Eliminates tonalities and reduces overall sound pressure levels