Setting a benchmark in gearbox reliability with advanced plain bearing technology

Hydrodynamic plain bearing technology is redefining wind turbine gearbox design, offering a more compact, cost-efficient and robust alternative to traditional roller bearings. With proven field performance and next-generation innovations already in development, it is setting new standards for reliability in modern drivetrains.

Since geared drivetrains are widely used in wind turbine applications, gearboxes have traditionally been equipped with roller bearings in all positions. In the early 2010s, feasibility studies began exploring the use of hydrodynamic plain bearings for these demanding conditions and their potential advantages quickly became evident.

Hydrodynamic plain bearings enable a more compact design due to their low radial space requirements, allowing for more torque-dense gearbox

configurations within the same footprint. In addition, their simpler architecture, featuring fewer components, supports more efficient production and assembly processes, making them a cost-competitive alternative.

They also offer improved dynamic performance, as their inherent robustness and excellent damping characteristics help absorb vibrations, reduce dynamic loads and contribute to smoother operation and potentially longer service life.

Intelligent design, robust material and system integration

Hydrodynamic plain bearings operate by forming a lubricating film that separates the sliding surfaces. This enables low friction, wear-free and highly reliable force transmission. Hydrodynamic pressure builds up when the lubricant is drawn into the converging gap between the moving surfaces. The bearing's load capacity depends on its geometry, oil viscosity and operating speed.

During normal power production, plain bearings in wind turbines typically operate in a fully hydrodynamic regime. However, non-production conditions, such as start/stop cycles, idling or single-blade installation, can temporarily result in mixed lubrication, where limited surface contact may occur.

For this reason, robust material selection and close coordination of system-level design are essential. Components are developed as part of an integrated system that considers operational behavior and strategy to anticipate

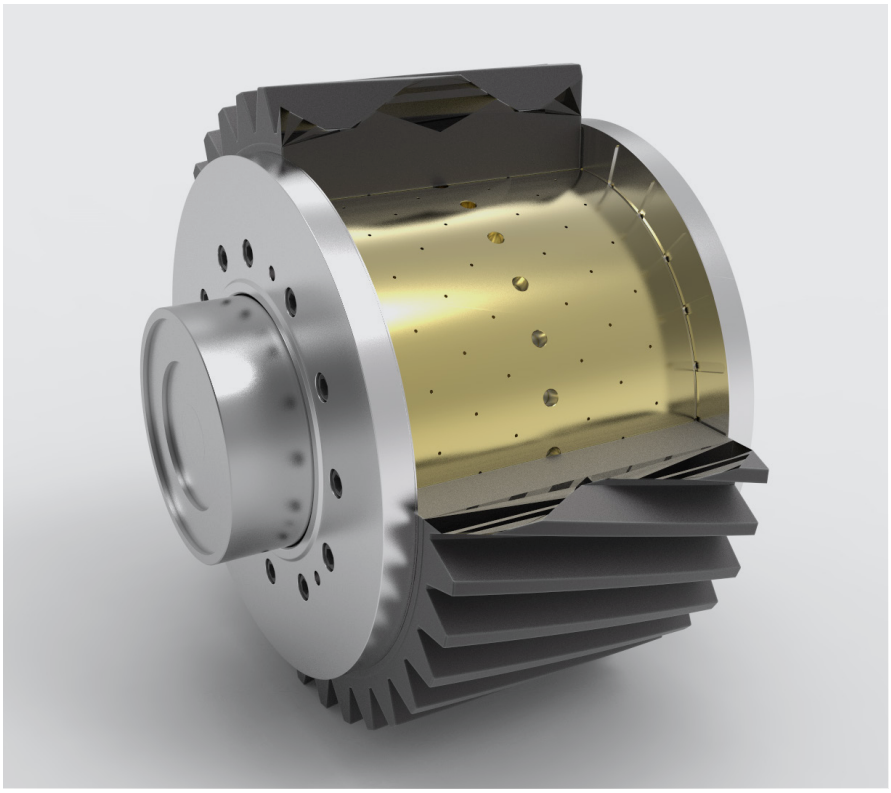

Figure 1: Dual film plain bearing for planet bearing position

edge cases and ensure reliable performance throughout the turbine lifecycle.

Dual film technology: a competitive and efficient solution

By the end of 2025, ZF Wind Power had installed more than 36 GW of gearboxes with plain bearings. During the initial development phase, it evaluated plain bearing solutions for both the position of the planet and the high-speed shaft. After successful demonstrator testing, the planet position was strategically selected for first product implementation, combining technical feasibility, system relevance, reliability and competitiveness.

This results in an advanced dual-film plain bearing design using a floating bronze sleeve positioned between the planet pin and the planet gear. Two hydrodynamic gaps, pin-to-sleeve and sleeve-to-gear, distribute sliding speed and ensure operational stability and robustness.

The outcome is a competitive and efficient system engineering solution that integrates multiple performance advantages. The bearing design, lubrication strategy, and gearing are developed as a fully interconnected system, ensuring optimal interaction between all components.

This approach enables a cost-effective and efficient planet-bearing solution while supporting smooth adaptation to the full range of intended turbine operating conditions.

Intelligent design choices combined with robust material selection help minimise the risk of bearing-related failures, ultimately reducing the likelihood of turbine downtime.

Inspection of plain bearings from prototype gearboxes operating in the field over multiple wind seasons has shown no measurable wear, confirming stable, degradation-free performance.

ZF's fleet monitoring indicates that plain bearing issues occurred only in a very limited number of isolated cases and primarily during or shortly after the commissioning phase. No consistent patterns were found regarding gearbox type, customer profile or site conditions.

Root-cause analyses consistently linked these events to unintended operational factors, such as major oil supply interruptions or very severe contamination in the lubrication system. Importantly, none of the cases were related to bearing design or material selection, underscoring the intrinsic robustness of the technology.

An analysis of the track record of ZF Wind Power plain bearing technology concludes that plain bearings on planet position have an excellent reliability in wind turbine gearbox applications, covering all intended operating modes. However, special attention should be taken during phases of the turbine lifecycle, where manual interaction with the oil system takes place for commissioning, maintenance and so forth, to avoid unintended oil supply conditions.

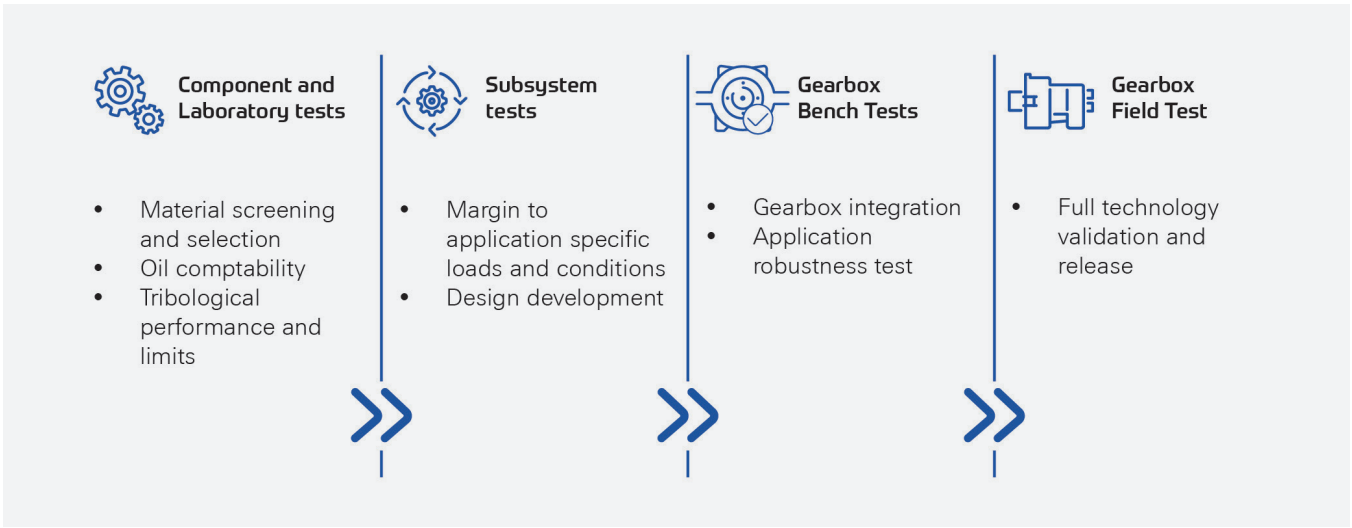

Figure 2: The next-generation plain bearing technology is validated in a systematic way

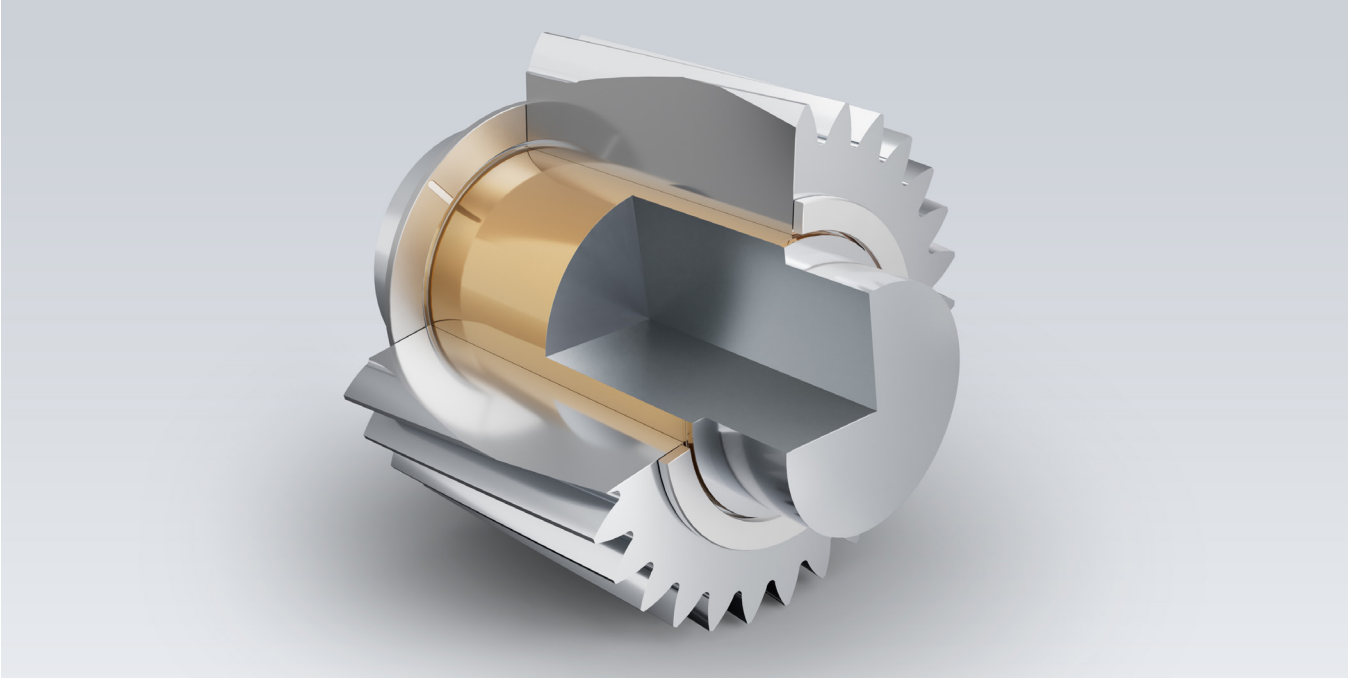

Figure 3: Single film plain bearing for planet bearing position

Strengthening drivetrain reliability and competitiveness

ZF Wind Power continues to advance plain bearing technology for wind turbine gearboxes. Building on years of in-house expertise and close system cooperation with partners, the company has designed and industrialized the next generation of plain bearings, further strengthening drivetrain reliability and competitiveness.

The new concept for the planet position is a single-film plain bearing, in which the bearing material is applied directly to the planet pin using a laser cladding process.

Jointly developed with technology partners and validated within the full drivetrain system context, this solution maintains the proven reliability of the dual-film design while enabling higher load capacity, reduced bearing size and improved cost efficiency.

Proven performance: the next-generation single-film plain bearings

The company has executed a comprehensive and well structured validation program to demonstrate the capabilities of its next-generation single-film plain bearing technology. The trajectory spans all development stages: from early laboratory investigations to component and subsystem testing, followed by full-scale gearbox evaluation.

A key milestone involved adapting a 4 MW SHIFT modular test gearbox platform by replacing the original plain bearings with the new single-film concept. The bearing dimensions were deliberately reduced to challenge the design and verify its increased load-carrying capability.

This configuration enabled ZF Wind Power to explore the full operating envelope and evaluate performance under demanding, real-world loading conditions.

Throughout the gearbox robustness tests, the single-film bearings consistently demonstrated stable and reliable behavior. They withstood significant overloads as well as challenging scenarios such as single-blade installation. In parallel, ZF Wind Power completed an in-depth qualification of the laser cladding process, which is an essential element of the bearing's manufacturing route.

With component, subsystem and full gearbox testing successfully finalized, the demonstrator gearbox has now progressed to field validation. This phase delivers long-term insight into real operating behavior and confirms the technology's performance under live turbine conditions.

Together, these results confirm that the single-film plain bearing concept delivers the robustness, reliability and performance required for today's increasingly powerful wind turbine drivetrains.

Building on this successful validation, the technology marks an important milestone for the SHIFT modular gearbox platform, further strengthening its competitive, reliable and efficient design. With the development program completed, shipment of first serial gearboxes is planned for 2027.

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About the company

ZF Wind Power is a global leader in technology-driven manufacturing and a major provider of wind turbine gearbox solutions and services.

Since entering the wind industry in 1979, the company has delivered more than 90,000 gearboxes, powering over 220 GW of mainly high-performance wind turbines worldwide.

As a forerunner in modular drivetrain innovation, ZF launched its SHIFT modular gearbox platform in 2016, setting benchmarks in scalability, reliability and efficiency.

With its compact, high-performance designs, SHIFT has enabled more than 65 GW of installed wind capacity, reinforcing ZF's leadership in the onshore segment and shaping the next generation of intelligent drivetrain architecture.

The team pioneered the world's first high-performance offshore wind turbine gearboxes and continues to deliver the next generation of offshore powertrains through close collaboration with its partners.

Today, they operate the world's largest installed base of +8 MW offshore turbine gearboxes, underscoring its leading position in the global offshore market.