Optical sensing boosts the reliability of wind gearboxes and drivelines

Gearbox integrated optical sensing is redefining the way gearboxes and drivelines are monitored and measured, leading to a new era of unprecedented reliability. By precisely measuring real-time torque, and planet load sharing, optical sensing provides a complete overview of the gearbox's health and performance. Strengthen asset management with the remaining useable life predictions of all driveline components based on the measured operating conditions. By optimizing operation and maintenance, wind turbine operators can significantly reduce the levelized cost of electricity (LCoE) and extend the lifespan of their complete driveline.

As wind energy technology continues to advance, turbines are growing in size and complexity. This evolution is supported by a shift in operational responsibility towards original equipment manufacturers (OEMs). This development requires gearbox manufacturers to adapt to evolving demands and logistic constraints.

To achieve this, gearboxes are being designed with higher torque density, incorporating multiple planetary stages with increased planet count per stage. Additionally, integrated hybrid drive systems are emerging as a cost-effective and space-saving solution, consolidating various components into a single pre-commissioned unit.

Hybrid drivelines, more complex gearbox designs and the already complex nature of monitoring wind turbine gearboxes, drive the need for more advanced life monitoring of wind turbine drivelines. Together with the trend towards the delivery of pre-commissioned, high torque density hybrid drivelines, reliability is the major topic for manufacturers.

The delivery of pre-commissioned drivelines also marks a shift in warranty and maintenance responsibilities towards driveline manufacturers, increasing the need to know exactly how drivelines in turbines are operated.

Fiber optical sensing of rotating equipment

Fiber optic sensing has emerged as a valuable tool for monitoring wind turbine blades and other structural components. However, its application in rotating parts of wind turbines has been limited due to early technological constraints.

Sensing360 has transformed this landscape by successfully combining optical fiber sensors with rotating equipment monitoring. Leveraging the optical advantage to easily integrate many passive strain sensors with the condition monitoring expertise of bearings, gearboxes, and drivelines.

Addressing the need for more advanced monitoring of bearings, gearboxes, and drivelines, Sensing360's optical sensor solutions are able to measure exact loads and torque of rotating equipment during operation.

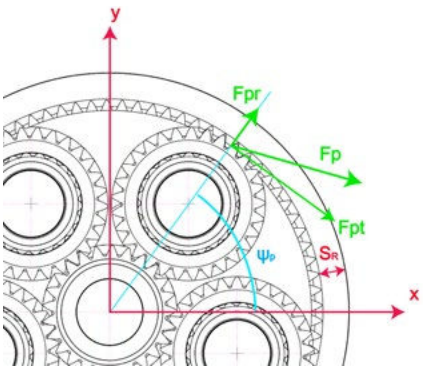
Real time measuring and recording of the accumulated damage caused by the impact of variable operating conditions on the asset under consideration makes it possible to predict the risk of failure of that component.

Sensing360's solution makes it possible to:

1. Detect premature bearing and gear failures before they impact the operation
2. Predict the probability of a gearbox fatigue failure given its operating history

As mechanical fatigue life is limited by 'how much a component is stressed and for how long', an exact consumed versus remaining lifetime statement is given based on exact operation conditions for that specific driveline. Making these key operation conditions available improves designs, increases uptime by monitoring and asset management and optimizes energy production of turbines.

These optical sensors convert the minuscule changes in the light waves inside an optical fiber into an ultra-accurate stream of strain and temperature measurements. The sensors are immune to various strong sources of interference in the turbine environment, can withstand natural phenomena such as lightning strikes which



can damage or disable electronic systems, and are smaller and lighter than their electronic counterparts. This makes them ideal for robust and cost-effective implementation. Next to these fundamental robustness features, higher sensitivity and accuracy is achieved, through detailed multi-point measurements originating from one optical fiber sensing cable.

Sensing360's first rotational optical solution in wind energy is the implementation of these sensors directly on the outside of the stationary planetary ring gear of a gearbox, called GEAR-UP. With the sensitivity of optical sensors, it is possible to measure input torque, speed of rotation and planet load sharing via deformation measurements directly on the outside of the gearbox.

This is done without the need for batteries, wireless communication, power transfer and shaft installations used in traditional torque monitoring solutions. This simple, robust, and accurate optical sensor solution has been validated during multiple test campaigns since 2019, including a one-year field demonstration at the US National Renewable Energy Laboratory (NREL) at Flatirons campus, Colorado, together with Gamesa Gearbox.

Model driven data analysis

While data science tools provide valuable insights from large datasets, Sensing360 recognizes the importance of combining these tools with physics-based models. This approach ensures a deeper understanding of gearbox and driveline behaviour and facilitates the derivation of crucial operating parameters. These parameters are calculated across all turbine operating states, including rated power, idle, and trip events.

Early collaboration with original equipment manufacturers (OEMs) was instrumental in developing and validating these models, involving simulation and validation engineers as well as control system experts.

The planetary ring gear in a gearbox plays a pivotal role in the transfer of input torque from the wind to the generator, thus generating electricity. The gearbox transfers the input torque and speed of the main shaft via planet gears to the desired generator speed and related torque. The radial and tangential components of the planet gear forces deform the ring gear and are then transmitted through the body of the ring to the outside, and these strains are sensed by fiber optic sensors on multiple locations on the outer surface.

Proof of concept tests clearly showed at dynamic torque and speed conditions, that the individual signals from each fiber-optic strain sensor exhibited a strain peak when a planet meshed with the ring gear in the vicinity of the sensor. These repeating strain peaks allow for accurate recovery of the gearbox loading, and its distribution from the sensors.

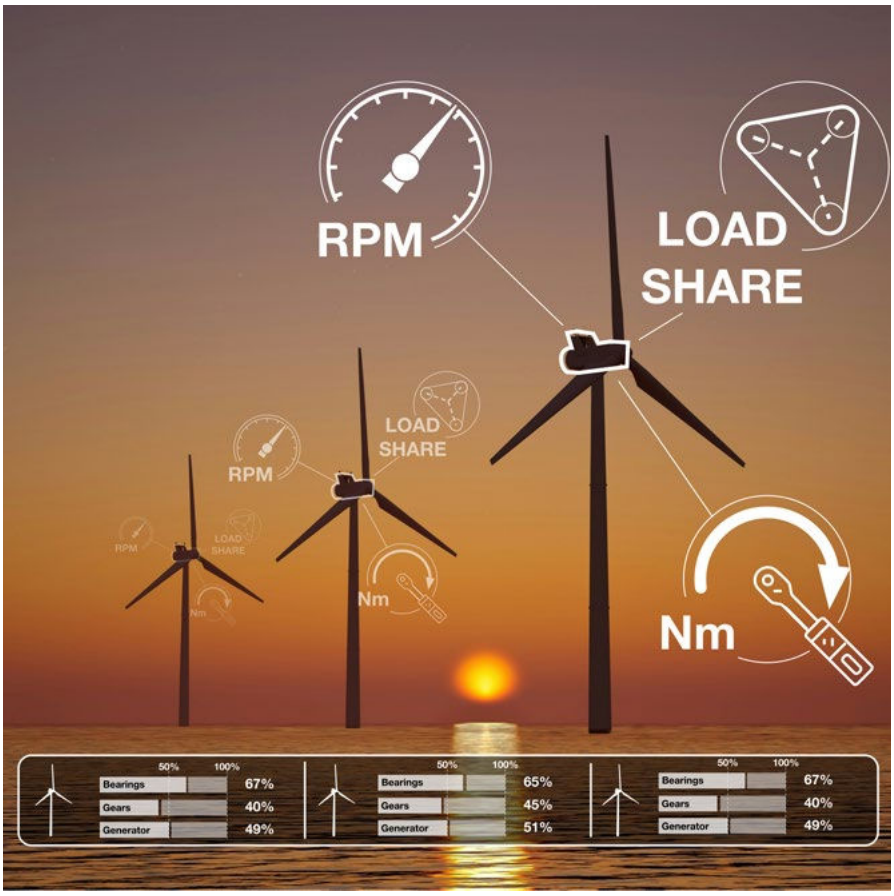
Optical sensors are not only instrumental in recovering exact gearbox loading, equivalent to input torque, but also provide valuable data on planet load sharing. This data is crucial in understanding how the load is distributed along the planets, impacting design and operation parameters.

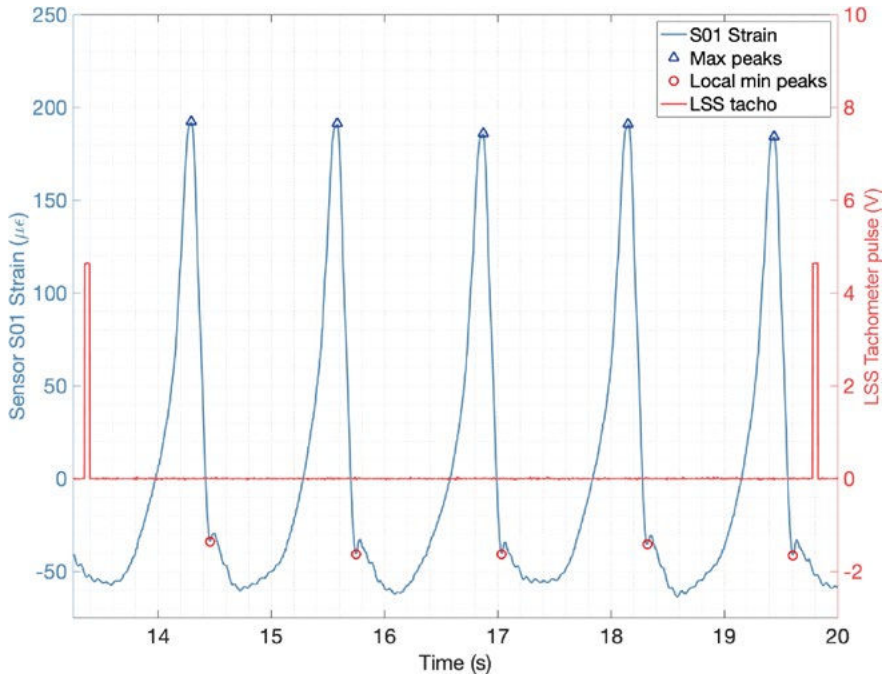
Detection of misalignments and failures becomes possible, as both scenarios lead to uneven load sharing. Pushed by the industry drive toward higher torque density for drivelines, one of the main design challenges of next-generation gearbox designs is sharing the load evenly between a high number of planets.

The load sharing is even fixed in the ISO standards as function of number of planets, at a higher number of planets these standards are conservative. Measuring the planet load sharing real-time in the turbine allows for lighter designs, higher torque density and condition monitoring of unbalance, misalignment, and planet bearings faults, including journal bearings.

Cooperate with your customers

From the beginning of the development, collaboration with OEMs proved to be crucial for the development of this robust, accurate, and easy-to-install optical gearbox monitor solution. GEAR-UP, available for both new and retrofit gearboxes, has evolved in terms of robustness, accuracy, simplicity, and ease of installation.





Sensing360 has been working towards a cost-effective solution for fleet installation and serial production. The optical planetary monitoring solution consists of a sensor module, edge software, and cloud and customer interfaces and visualization module.

Unlocking the potential for condition monitoring and operation optimization

Acquiring more field data allows for advanced monitoring for all the driveline components on consumed- versus remaining life, bearing, gear and teeth failure, and optimized production by using torque as control parameter. Performance modelling shows that up to 7% more energy output can be obtained from a complete park by leveraging load and consumed life estimations as control and maintenance parameters to improve overall production efficiency.

Currently, cooperation with customers continues to capitalize the potential on improved maintenance and operation. By disclosing the real operation parameters towards a cloud platform, new asset management strategies and control parameters are being discussed as for instance using planet gear load sharing for the condition monitoring of journal bearings and gears.

Secondly, failure risk of all the driveline components individually or as a whole are derived and used as input parameter for maintenance strategies. A third promising track is extending these failure risks and consumed life calculation towards complete parks and use these during the assessment of a park after its initial warranty period; how much 'life' is used until now?

The final goal is to optimize energy production, use the operation loading as control parameter for optimized energy output or predicting output. By knowing the current and past operating conditions allows for predicting the future conditions and failure risks, this enhances the possibilities for control. Think about using those inputs during storm conditions; knowing exactly how much your gearbox and driveline is being stressed allows for better turbine control: increasing output, reducing damages and increase overall performance.

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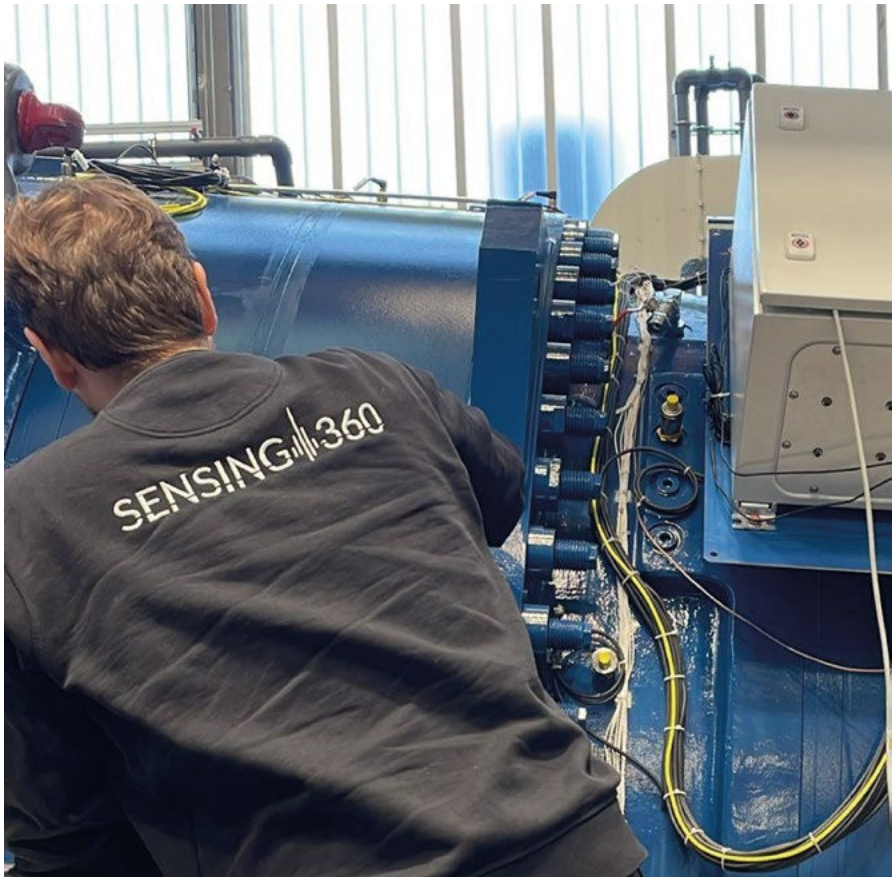

About GEAR-UP

In the dynamic world of wind energy, where reliability, cost and energy output are paramount, Sensing360's GEAR-UP solution emerges as a beacon of innovation.

By offering a robust and simple approach to monitoring torque, speed, and load sharing in driveline gearboxes, this technology is set to redefine industry standards.

With increased reliability, extended equipment lifespan, cost savings through predictive maintenance and optimized operation.

This solution stands at the forefront of enhancing the performance and longevity of drivelines exactly in line with industry trends.