Taking on Tight Margins in Wind Energy

Three Factors Influencing Gearbox Technology in Wind Turbines

Matthew Jaster, Senior Editor

Onshore and offshore wind turbines boast some of the most critical assets in order to run effectively. If the motors, bearings and gears fail, the result is expensive maintenance costs, operator safety concerns and the end of that warm, happy fuzzy feeling, according to Brett Burger, product marketing manager at National Instruments. "We don't often start with that warm, happy, fuzzy feeling at the beginning, but our goal is to get there by providing the hardware and software tools that are specific to the user's requirements."

The gearbox is largely considered the heart of a wind turbine, according to Fernando Catalão, chief WTG engineer at SMT Portugal. It converts the slow rotation speed and high torque of the rotor through the transmission in the gearbox to a high speed and low torque in the generator. In the same way that wind turbine companies request new concepts and higher quality gearboxes, the gearbox manufacturers ask subcomponents suppliers for advancements in bearings, heat treatment and lubrication systems.

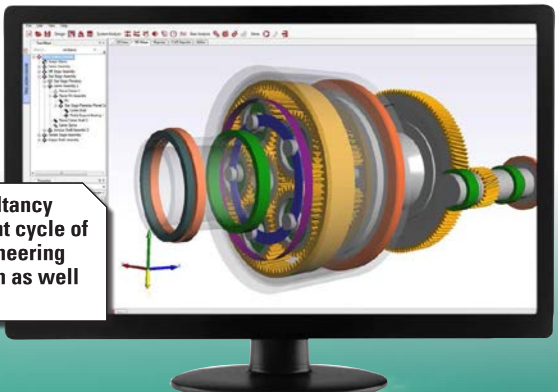
"The gearbox manufacturers and designers have learned lessons from other industries. Better maintenance regimes, condition monitoring/management, better oils and oil care have all played their part as well as powerful CAE software modelling, advanced manufacturing technology, improved materials and a greater understanding of the turbine operating environment," he added.

Companies like Smart Manufacturing Technology Ltd. (SMT), KISSsoft, Romax and National Instruments play a significant role in advancing wind turbine technology today. These companies recently addressed the key factors influencing gearbox technology such as meeting the challenges of gearbox design, properly testing the equipment and developing a condition monitoring system to improve gearbox performance and limit production downtime.

#1 Meeting the challenges in gearbox design

The predominant influencers on the design of wind turbine gearboxes have been driven by the requirements of the market itself. "This includes cost, weight, reliability and noise requirements," said Stephen Brown, vice president, engineering design at Romax Technology. "Bigger rotor diameters are increasing in popularity from OEMs. The resulting load and torque increases, combined with lower weight and cost requirements, are dominant driving factors in new product gearbox design."

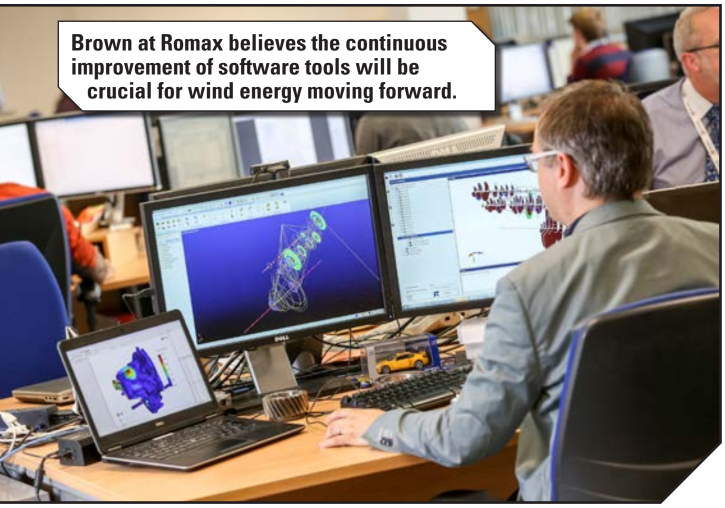
Catalão believes several factors play a role in improving gearbox design including reduced maintenance time/costs; simplified and modular designs; lighter weight; higher reliability components and lower manufacturing costs. "SMT has developed a wind turbine gearbox



SMT provides engineering design and consultancy services that cover the complete development cycle of wind turbine drivetrains with extensive engineering expertise in transmission and gearbox design as well as analysis and manufacture simulation.

for offshore applications that can avoid planetary systems and take into account the modularity and size of the components. This concept can decrease the costs of the manufacturing due to the simplicity of the shafts and a reduced number of components. Also, this gearbox design makes it possible to replace all components in place without the need to disassemble the gearbox from the nacelle, dramatically reducing downtime and repair costs," Catalão said.

The predominant point is the data collection and analysis to understand failure mechanisms, according to Brown. "These are ultimately fed into designs



Brown at Romax believes the continuous improvement of software tools will be crucial for wind energy moving forward.

(and software) to enhance reliability at the design stage. The continuous improvement of software tools through data integration, reports, supply chain, manufacturing and product management will be crucial moving forward."

For KISSsoft Gmbh, the engineering tools have evolved rapidly over the last five to ten years. All of the challenges involved in wind applications can be boiled down to managing design processes. "This requires a total system approach where designers are focusing on details and have little experience or exchange with manufacturing or quality control," said Hanspeter Dinner, consultant, EES KISSsoft Gmbh. This means training new engineers must go beyond the basics of the software design package. "We inform engineers on theoretical background, principles of gear and bearing design, conduct seminars on drivetrain technology and perform onsite design reviews," Dinner said.

Feedback from the load test to the design engineers is crucial. "Of highest interest is the correlation of the tooth contact patterns as predicted/calculated to what is observed in the field. Here, it is imperative that designers are closely involved with the testing and get access to the gears (and other gearbox parts) in the workshop," Dinner added.

#2 Testing Equipment

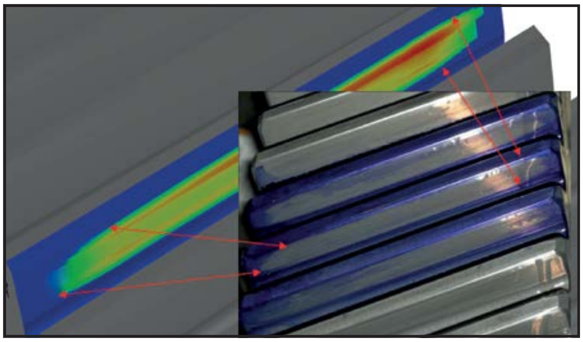
Testing is important in wind turbines because the margin between being profitable and not profitable is so slim. "It's a very tight margin," Burger said. "You're setting up government subsidies to get going, for example, and then driving down the costs of the technology over time as those subsidies roll off. It is important that when you deploy a standard wind turbine it will last as long as it can or in the case of a new technology on a wind turbine, you want it to be as efficient as possible so that it will catch on. I think in both those scenarios, testing is an absolute necessity."

National Instruments tests everything from control systems to structural testing (thermodynamics, structural engineering). "When you have your simulation model in the computer and your real model deployed in the field instrumented with sensors, the customer can compare the two and make sure what they expect to happen is actually happening. When those two line up we're back to that warm, fuzzy feeling again," Burger added. "When they don't line up, that's when engineering and part design get together and attempt to remedy any discrepancies."

Testing capabilities are one of the key ingredients if you want to be taken seriously in the industry, added Dinner at KISSsoft. "Running full load and overload tests are industry standard and a good correlation between analytical prediction of contact patterns and strain gage measurements are achieved nowadays. It is also relevant when purchasing/designing gearboxes not only to supervise the test itself, but also the assembly of the gearbox prior to testing (to see whether damages were present even before the test) and the disassembly after the testing (it is tempting to hide damaged parts from the customers or certification body's eyes). The key challenge in testing from a supplier point of view is to shorten times between test runs, that is, to shorten the time needed to install and de-install the gearbox in the test bench."

Brown agreed, "Full scale testing has been driven by certification agencies to make a requirement to validate design. It has also been used as a compliance validation following a gearbox rebuild that has already been in service. The industry is seeing three and four DOF (Degrees Of Freedom) test rigs emerging that provide close-to realist trials and results. Testing will always play an important role in the wind industry because of the costs associated with failure in operation, particularly offshore."

"Full scale testing is crucial for technological and system innovation because this kind of test makes it possible to see the potential weak points that can come to the surface for each component of the system," Catalão added.



The loaded tooth contact analysis (LTCA) in KISSsoft has been refined over several years and is now showing outstanding match to contact patterns observed in full load tests performed using a master and slave gearbox in back-to-back arrangement. Combined with the load spectrum calculation and the KHβ calculation along ISO6336-Annex E as required to obtain certification along GL guidelines, it is a most powerful, easy to use and accurate tool to optimize the load sharing and hence the power density of any wind gearbox. The above image taken from such a test confirms the comparability between load patterns from analysis and real world conditions.

#3 Condition Monitoring

The main objective of condition monitoring is to determine the current technical status of the component—the health of the gearbox. "Condition monitoring and failure analysis can be a vital tool to decrease/reduce the operation and maintenance costs, as well as, provide important information (sensors data) to predict upcoming failures," Catalão said.

In Europe, the condition monitoring system (CMS) is now mandatory for offshore, and factory-fitted to all new turbines, and it is becoming more common for onshore turbines in Europe as well as North America, with CMS increasingly being retrofitted in the field. "Early detection of gearbox problems saves operators a large amount of money, so understanding condition monitoring reports and being able to interpret the data can be cost-saving at the least, and performance improving at best," Brown said.

Dinner at KISSsoft wants to see an additional approach in the engineering analysis of gearboxes in the future. "We need to use statistical methods to predict MTTF (mean time to failure) or similar values. This is opposed to the current approach where for a 20 year lifespan a safety factor is calculated even though we all know the calculation methods are not valid or reliable for 20 years of operation. For the prediction of MTTF values, using only the theoretical approaches available in standards is not sufficient as they are often based on different concepts or different inherent failure probabilities. Here, feedback from the field (be it failure analysis or condition monitoring) needs to be considered and used as a basis to make predictions, as it is done

Determining root failure cause: Endoscope inspection of a wind turbine gearbox.

in other industries (helicopter or vehicle transmissions for example). Obviously, the condition monitoring approach has an advantage here as all data is readily available for processing and statistical analysis.

"Gearboxes have been around much longer than wind turbines," Burger said. "One of the advantages of the technology that is currently happening with the Industrial Internet of Things (IIoT), you can bolt on this high-end performance, computing node and not only do you have the ability to monitor the gearbox through its life, you can log data and determine how to improve upon it in the future."

National Instruments has customers that are the owners of the assets eager to plan and prepare for any unplanned outages. They also have customers that are gearbox manufacturers.

"The condition monitoring equipment becomes a black box of sorts for these customers, logging data in order to process hitches or spikes or additional anomalies in the equipment. The customer can then use this data to determine if the problem is environmental, something in the manufacturing process or problems with the initial design."

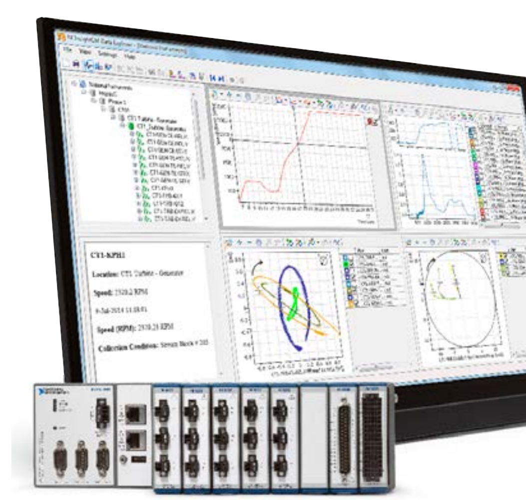
Never-ending innovation

While these three factors only scratch the surface of gearbox technology, the truth is the hardware and software tools available in this growing market are as dynamic as the equipment they are monitoring.

"The development process never stops," Catalão said. "This means that gearboxes will continue to be complex and highly-reliable components in the drivetrain of new wind turbines. This reliability, however, does not mean gearboxes will be completely trouble-free. Replacing a gearbox will still come at a very high cost. In other words, replacing a shaft or a bearing is cheaper and quicker than replacing the whole gearbox and engineers will opt for systems with better interchangeability for components."

Future integration between CAE software packages for design, manufacturing and testing will help close gaps in development loops and ensure an engineer's time is spent innovating rather than processing and migrating data," Catalão said.

The gearbox is the link between the rotor and generator, Dinner added. "Its design will be driven by those components, the gearbox has to fit in, that's all. So, the requirements on the gear-



box will evolve with new technologies applied there. In testing, we expect more transient tests to be done besides the standard load and overload tests. Also, application of hub loads like bending moments or axial forces is something we expect to happen more often in the future."

Brown at Romax said that industry is looking towards life prediction as a dominant factor in wind turbine operation. "The benefits include operation and maintenance cost management, outages and service intervals that can be easily predicted and managed, the education of reliability factors, the opportunity of increasing power production through control system refinements and the opportunity of asset life extension."

Burger at National Instruments sums up the future of hardware and software tools like this. "Right now, we're brownfield. There's a huge inventory of commissioned assets out there," he said. "10 to 15 years from now, you're going to see more of the sensing technology, the processing and measuring technology built directly into these assets. It will be more common in the future to have a smart or intelligent gearbox that can self-diagnose problems. This will make it so much easier for a gearbox manufacturer to alert a wind farm when turbine components need to be shut down and serviced immediately in the field."

National Instruments InsightCM Enterprise is a software solution for online condition monitoring applications with specially designed and cost-effective hardware options for asset health monitoring.

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Early Wind Turbine Developments

In the early 1980s, wind turbines went into mass production to be used as commercial generators of energy. Since then, a wide variety of wind turbines emerged in the market. "The Danish wind turbine concept, three-bladed, fixed speed, stall-regulated turbine became the dominant model in the market at rated power levels of less than 200 kW. As installed capacity has increased, wind energy technology has evolved towards machines with longer blades and higher power ratings," Catalão said.

This increase in capacity has led to more stringent regulations and the need for the gears and gearboxes to keep pace and adapt to these requirements. "Gearbox manufacturers therefore have been pushed to design and develop more reliable and competitive products," added Catalão.

In general, the gearboxes can be separated in low, medium and high speed applications with one, two or three stages respectively. "A wide range of other designs have been tried and applied, e.g. compound planetary (e.g. by RENK), differential planetary (e.g. by Bosch Rexroth), helical gearboxes with multiple pinions driving several generators (e.g. by Clipper or Winergy) and even gearboxes including bevel differentials (e.g. by Kowintec)," said Dinner at KISSsoft Gmbh.

"Other non-standard gearbox designs would use flexible planet supports, hydrodynamic bearings instead of rolling bearings or double helical planetary gears. Still, two planetary stages plus one helical stage is the industry standard, ratios are now going up to e.g. 1:110. We do see a trend towards medium speed gearboxes where the generator is in line with the gearbox, resulting in lower generator speeds and less difficulties to align gearbox and generator (e.g. SCD 3 MW and 6 MW by Aerodyn, Multibrid, Winergy HybridDrive and Moventas Exceed)," Dinner added.

In the early stages of wind turbine development, these gearboxes were little more than adaptions of those used in industrial or agricultural applications with a very simple configuration; two or three stage spur gear drives between the input and output. "Modern gearboxes are now complex and highly efficient drivetrain systems and their reliability in recent years has significantly improved," Catalão added.

The wind industry has long debated the benefits of both direct drive (DD) and geared solutions for wind turbine drivetrains. DD solutions became increasingly popular following reliability challenges from MW-scale gearboxes. "As it would currently seem, the industry is swinging towards geared solutions (high speed output-generator for smaller MW machines and medium speed for larger," said Brown at Romax Technology. "This could be explained by improving reliabilities being enjoyed as well as better cost competitiveness, provided by geared drivetrains."