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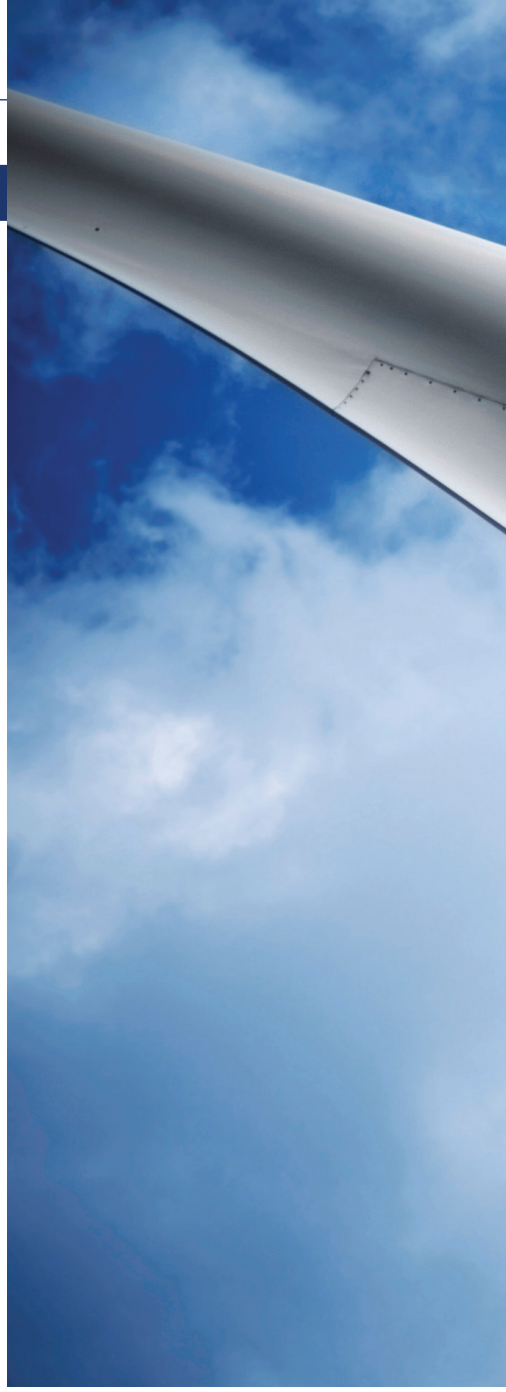
Extending the life of wind-turbine components

Specialized PVD coatings, nitriding increase the durability and lifespan of turbine components.

By Jeff Elliott



With the increasing demand for carbon-free renewable energy, more companies are turning to wind power as a source for their energy needs. Although this presents a good deal of potential for the manufacturers of wind turbines and their components, the technological challenges of providing a reliable product that operates with minimal maintenance or repair is increasingly daunting.

That is because enormous forces are at work on the individual internal components.

Turbine shaft bearings, planetary and sun gears, and rotating shafts, for example, operate under high-load conditions that involve direct metal-on-metal contact, often in poor lubricating conditions. With components increasing in size, these forces only become more extreme.

When this occurs, turbine components made of hardened steel or metal alloys can still break down as a result of extreme wear, scuffing, surface fatigue, pitting, and galling.

Given the sheer size of wind turbines, wind-farm operators must bear significant costs for overhauls that often involve logistics involving cranes for on-site repairs.

"When you have to bring a crane to change the main shaft bearing, for example, it is not only the cost of the new bearing but also the total work to exchange the part," said Dr. Florian Rovere of Oerlikon Balzers, a company that produces specialize PVD coatings for components in North America.

"It can quickly become $100,000 or $200,000 for the overhaul," Rovere said. "So all of a sudden, your green energy becomes super expensive, which is why wind-farm operators really want to extend the longevity of the components as much as possible."

To address this issue, coatings and surface treatments can significantly extend the service life of wind-turbine components. Today, this is being accomplished through the application of specialized physical vapor deposition (PVD) coatings and nitriding treatments that increase surface hardness and durability.

By applying coatings optimized for these types of punishing environments, components benefit from increased surface hardness and a much lower coefficient of friction. As a result, these critical parts do not have to be replaced as frequently, if at all, reducing maintenance and unplanned downtime while improving wind-turbine performance.

PVD COATINGS

Physical vapor deposition encompasses a wide range of vacuum deposition methods. It essentially covers components with thin coatings to increase their surface hardness and durability, lower the friction coefficient, and resist corrosion.

Coatings and surface treatments can significantly extend the service life of wind-turbine components. (Courtesy: Oerlikon Balzers)

By applying components with PVD coatings designed for such demanding conditions, not only is the surface hardness and durability increased, but essential parts are far less likely to fail, if at all. As a result, maintenance and unexpected downtime are drastically reduced.

A specialized PVD coating that is particularly effective is Balinit C, which can be applied in thicknesses of 0.5 to 4 micrometers on roller bearings and gear parts.

The WC/C ductile carbide carbon coating has a high load-bearing capacity, even when used with insufficient lubrication or dry contact.

Due to its low-friction coefficient, the coating can drastically reduce fretting corrosion and pitting. By forming an effective barrier between metal-on-metal contacts, the coating reduces metal structural damages such as white-etch cracks and fatigue failure.

According to Rovere, there are alternatives to PVD coatings that are at times used on wind-turbine components like black oxide.

Black oxide is a coating produced by a chemical reaction between the iron on the surface of a ferrous

As a result of specialized coatings, these critical parts do not have to be replaced as frequently, reducing maintenance and downtime while improving performance. (Courtesy: Oerlikon Balzers)

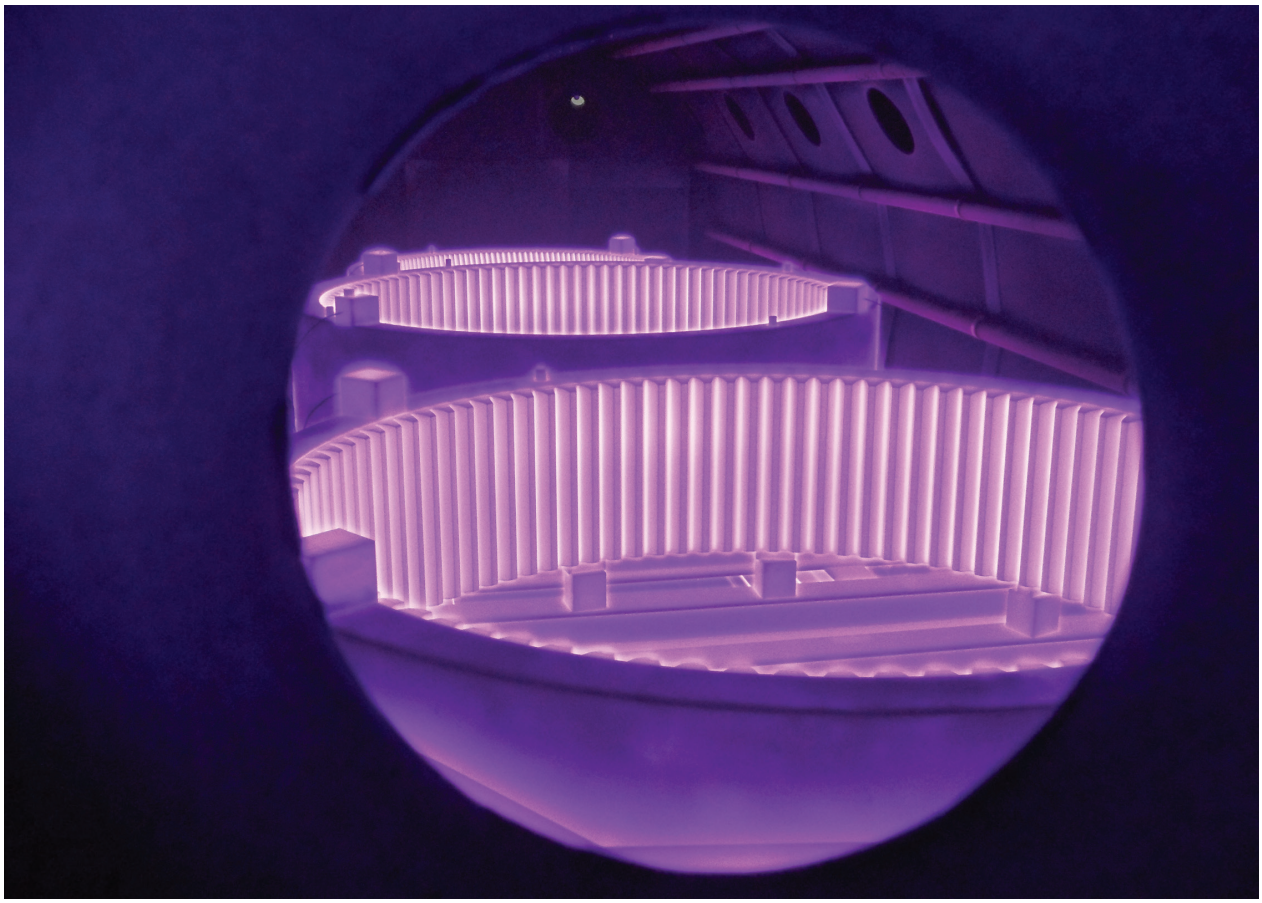
metal and oxidizing salts. After a post-treatment with oil, the surface provides protection against corrosion, improved lubricity, and prevents galling during metal-to-metal interactions.

However, black oxide is not durable and can be worn away quickly in repetitive, high-load applications.

NITRIDING

There are limitations to the size of products that can be coated with PVD, such as the ring gears in modern wind turbines that can measure up to two to three meters in diameter.

For these types of large gears,



Nitriding is a heat-treating process that diffuses nitrogen deep into the surface of a metal to create a case-hardened surface. (Courtesy: Oerlikon Balzers)

Rovere said a nitriding process can be used instead to increase the surface hardness of the metal.

"Nitriding is a heat-treating process that diffuses nitrogen deep into the surface of a metal to create a case-hardened surface," Rovere said. "Because it is not a coating, it does not affect the overall dimensions of the component."

Although traditional gas nitriding costs less, plasma nitriding has the advantage of making the treatment more precise by minimizing warpage and distortion while achieving a higher load-bearing capacity.

In an FZG pitting test, Balitherm Ionit, a plasma-nitriding process from Oerlikon Balzers, exhibited five times less roundness deviation and seven times better planarity than gas nitriding on a two-meter diameter ring gear.

Another potential application for plasma nitriding is for treating the surfaces of large bearing cages used with wind-turbine bearings to increase the sliding wear resistance against the rollers.

The process can be used on components up to three meters in diameter, 10 meters in length, weighing up to 40 tons.

"Compared to gas nitriding, the tolerances for roundness, planarity, and parallelism can be adhered to much better, even with such large parts as the ring gears, and that is of great importance for the service life of a system in which enormous forces are at work simply because of its size," Rovere said.

Jeff Elliott is a Torrance, California-based technical writer. He has researched and written about industrial technologies and issues for the past 20 years. For more information, go to www.oerlikon.com/balzers.

Monitoring wind in cold climates

The ability to keep track of potential ice build up on turbine blades can significantly reduce maintenance costs.

By Michael Clarke

Wind-farm operators in cold-weather climates such as Canada, Sweden, and parts of the United States are confronted with unique operating challenges. When faced with extreme temperatures of -20 degrees Celsius or lower, atmospheric icing becomes the leading cause of a variety of challenges. And in cold-weather climates, where icing is a frequent occurrence for up to six months of the year, wind-energy projects are often viewed as less feasible or less successful.

The most common challenges created by ice accretion are: reduced production power, reduced lifespan of equipment, and public safety concerns. In its recent study, Development and Validation of an Ice Prediction Model for Wind Farms (2016), the TechnoCentre Eolien summarized: "During an icing event, the presence of ice on turbine blades alters their aerodynamic properties, which reduces their efficiency and generates vibrations. The latter magnify the material fatigue of turbine components, which ultimately compromises their service life. Furthermore, turbines must occasionally be shut down to prevent the risk of ice throw, which can cause injuries to wind-farm employees or citizens residing in proximity."

Fortunately, a variety of technologies are mitigating these common challenges, and leveling the playing field between cold- and warm-weather climate operators.

CHALLENGE NO. 1: REDUCED PRODUCTION POWER

At any given time, a change in vibrational and/or torsional force on the turbine blade can result in a loss of production power. In cold weather, where ice buildup is frequent, changes in torsional force are commonplace. Many systems exist to detect such changes and would traditionally trigger an automated shut-down cycle. Such a cycle lasts for a period of time, which lengthens each time the turbine attempts to restart, detects a continued change in torsional force, and triggers the next shutdown cycle.

While this shutdown mechanism is beneficial in reducing unnecessary wear on the equipment, it's hugely detrimental to power production. In cold weather climates, ice build up can sometimes last for days, during which time the shutdown cycle has continued to increase to the point where, when the ice finally melts, the turbine may not be triggered to start up again for several hours. This results in significant losses in power production.

According to a six-year CanmetENERGY Ottawa (CEO) study, the average loss factor of wind-energy production in cold weather climates is 3.9 percent. This translates to an estimated total loss of 959 GWh per year across Canada, representing $113 million in lost revenues country wide (Natural Resources Canada, 2017).

In colder climates, turbines must occasionally be shut down to prevent the risk of ice throw, which can cause injuries to wind-farm employees or residents in proximity. (Courtesy: Campbell Scientific Canada)

CHALLENGE NO. 2: REDUCED LIFESPAN OF EQUIPMENT

In cold climates, operation and maintenance requirements are far more demanding than in warmer temperatures. IEA Wind's recent publication, Wind Energy Projects in Cold Climates, affirms the economic risk of "increased maintenance costs due to low temperatures and the likely higher-than-average downtime between repairs caused by turbine inaccessibility" (2017).

Ice greatly affects the longevity of turbine blades, nacelles, and motors. As we know, ice build up will create an imbalance in the forces acting on the turbine. Depending on the blade orientation, if one blade has accumulated ice, it can begin pulling outwards, putting additional strain on the gearbox. In addition, icefall has the potential to affect surrounding blades, as well as the roof of the hub, causing significant damage.

Performing maintenance on wind turbines is an additional challenge due to potential inaccessibility. Heavy snowfall can make accessing wind-farm roadways impossible with regular service vehicles. Implementing a regular snow removal schedule during winter months, and/or investing in specialized equipment, will eliminate accessibility issues; however, both options require significant capital expenses.

CHALLENGE NO. 3: SAFETY CONCERNS

Ice throw from turbine blades is a significant concern for public safety. A turbine with an 80-meter blade diameter and 70-meter hub height has the potential to throw a piece of ice a distance of 225 meters. And as

the number and height of installed turbines increases in and around urban areas, public safety becomes increasingly important. In well-established markets like Germany, where the density of wind turbines is much higher than that of North America, it has been mandated that ice detectors be present on all turbines. As the North American market gets denser, it may be subject to similar future mandates.

Operator safety is another serious concern. Ice throw and ice shedding (where fragments of ice and snow fall from the blade) are a risk for anyone working in close proximity to turbines.

BEST PRACTICES

In February 2017, IEA Wind published a study of recommended best practices for wind-energy projects in cold climates. Within the study, it specifically outlined a variety of components and technologies aimed at mitigating the specific challenges outlined above. In particular, the following components and technologies were addressed:

Materials and components: Adapted for low-temperature applications such as low temperature alloys and special elastomers instead of standard rubber.

Welding procedures: Should all be completed with special low-temperature flux.

Lubricants: (Grease and oils) and hydraulic fluids suitable for low temperature.

Heaters: For components and lubricants, e.g. for generator, gearbox, yaw-and-pitch systems, control boxes, converters, and transformers.

- Blade heaters are an option that work to eliminate ice buildup al-

According to a six-year CanmetENERGY Ottawa (CEO) study, the average loss factor of wind-energy production in cold weather climates is 3.9 percent. (Courtesy: Campbell Scientific Canada)

together by forcing hot air directly into the blades. While highly effective in reducing ice formation, they are an expensive option and require a power source to run, which doesn't help to reduce power production.

- Nacelle heating to allow a reasonably safe and comfortable working environment for turbine maintenance.

Cooling system: Suitable for low-temperature operation to avoid icing of condensers or other systems.

Control system: Designed with low-temperature features, such as preheating of components and subsystems during cold start after a grid failure.

Measurement systems: Including heated sensors. It's recommended that the measurement system support structures, such as mounting booms, are also heated.

Ice detection systems: To safeguard nearby personnel and infrastructure from ice throw and to safeguard the wind turbine against rotor unbalances and potential damage to the turbine. Ice detectors are one of the least expensive, low-maintenance, and long-lasting solutions available today. Once attached to the hub or a nearby meteorological tower, they work to detect ice accumulation via an ultrasonic axially vibrating tube that senses changes in mass as a result of ice accretion. They act as an early detection system, allowing operators to shut down turbines immediately and then restart them once the ice has melted, significantly reducing operational downtime.

Blade ice protection technology: To prevent down time, mitigate ice-throw risks, decreased iced-blade noise emissions, and reduce potential increased turbine loading due to icing. Ice-phobic coatings are another potential solution: A coating or spray is applied directly to the blades, which discourages the accumulation of ice. The lower initial cost of application makes these coatings an effective solution, though ongoing maintenance and continued applications are required.

Cameras: An effective complementary tool for improving safety around wind farms. Outdoor cameras built to withstand harsh climates are installed on the hub of the turbine, where they provide visual confirmation that corroborates data from other prevention methods.

The extreme temperatures of cold-weather climates present many challenges to wind-farm operators. Continued collaboration between manufacturers and energy producers will promote new and innovative solutions. These will work to shape the wind-energy landscape, increase the viability of North American cold-climate wind-energy markets, and create opportunities for operators to become leaders in renewable energy.

Torque loading: Standards have limits

Part 2: Specific industry standards for wind-turbine drivetrains include gear-failure modes.

By Paul Baker and Doug Herr

(Editor's note: This article on torque loading is presented in two parts. Part 1 on how drivetrain components are important in analyzing component performance appeared in the January issue of Wind Systems.)

The IEC standard 61400-4 (2012) is the latest standard for wind-turbine drivetrains. Although AGMA/AWEA 6006-A03 was reaffirmed in 2016, 61400-4 is one of the most used industry standards.

61400-4 expands on previous standards, and includes new gear-failure modes to be taken into consideration for micro-pitting and subsurface initiated fatigue. One notable change is the requirement to inspect 100 percent of manufactured gears for surface temper, rather than only a sample.

Minor changes also were made to gear rating safety factors. Three goals were established for the inclusion of dynamic drivetrain analysis:

- Verify and confirm the modeling of the gearbox in the WTG aero-elastic model.
- Verify the occurrence of gearbox-specific loads due to dynamic amplification.
- Assess influence of boundary conditions on the internal gearbox loading.

The standard includes minimum requirements for dynamic drivetrain analysis documentation and validation from field or dynamometer testing. Gearbox testing requirements are more stringent. The scope of the test campaign is agreed upon by the gearbox manufacturer, the wind turbine manufacturer, the bearing manufacturer, and the certification body.

The new standard also requires certain parameters to be measured while defining minimum run times for each defined load step. A "robustness test" which mentions "elevated loads" is required, but the details are left to manufacturers. Field-testing also is a new requirement for gearbox testing. It requires certain parameters to be measured during selected events such as high winds, shutdown events, emergency stops, and low voltage ride-through.

For bearing rating calculations, 61400-4 introduces several new and well-defined design requirements. A substantial portion of the gearbox design section of the standard focuses on bearing design and reliability. The standard states the steel quality of bearings shall meet ISO 683 requirements with regards to chemical composition, steel cleanliness, steelmaking process, heat-treatment and micro-structure.

This is an important improvement over previous standards. ISO 281:2007, the calculation standard most used for bearings, requires only steel bearings of good quality. A definition for good quality, however, is missing.

The updated standard requires bearings to be rated using the internal load distribution from detailed models such as ISO/TS 16281. The previous version did not specifically mention how to account for the internal load distribution. This may have an impact on accurately predicting the life of planet bearings, which are subject to constant tilting moments in the 3-point design.

ISO/TS 16281 requires extreme design loads to be specified, and maximum load reversals and accelerations should be included in statistical summaries and identified separately with supporting time series where possible. The standard recommends using:

- Rainflow counting.
- Load revolution distribution.
- Load duration distribution.
- Extreme load matrices to include transient loads into the design load cases.

While these tools provide well-accepted processes for documenting all load cases, they are still fatigue based (duration sensitive), and likely to be under-represented when calculated over the estimated turbine life.

STANDARDS HAVE LIMITS

Ultimately, it is difficult for the standards to adequately quantify all the conditions in a highly variable, dynamic loaded wind turbine. The standards can identify the need to better quantify loading. A methodology used for this is shown in ANSI/ABMA Standards, which allows bearing manufacturers to adjust the theoretical L10 life with life-adjustment factors to try to capture non-rolling contact fatigue failures.

These factors take into account the desired life, the specifics

of the bearing design, and the actual application's conditions. Life adjustment factor A1 is reliability, allowing for a tighter than 10 percent tolerance on failure in the design life. Material factor is the A2 adjustment, allowing for differences in material, melting, and processing for the desired performance. The final adjustment factor is application or A3. This takes into account lubrication, misalignment, temperature, load-zone factors, low loads, and more.

For wind, this A3 factor may be the most difficult factor to consider since the variables are so numerous and are hard to model or test. The A3 factor is what brings the results of the damaging transient loads into the equation. Unfortunately, these are not well defined in the load cases and must be estimated in the A3 factor.

It is impossible to predict the amplitude and frequency of transient loads on individual turbines; farm-to-farm variation can be significant. The standards leave it up to turbine manufacturers to make the decision of how much safety factor are built into their systems. It is not simply a case of making the product cheaper; it is a factor of design compromise. They must balance building the lowest cost turbine (to gain a lower cost of energy) with the most reliable production possible. Standards are not likely to ever "solve" the issues of premature failures. Other solutions must be brought in to help extend the life of turbine drivetrains. They might include:

- Surface finishes above the standards.
- Torque control solutions.
- Better oil and filtration.
- Solutions to better manage the damage of transient loads.

In conclusion, the continuing problem with definition and standardization of severe transient loads is truly a work in progress for the industry. Much more needs to be done in order to quantify and calculate the damage caused by these short-term but potentially life-limiting conditions. For more details on this topic, look for our white paper to be released in early 2018.

SOURCES:

1. AGMA/AWEA. (1996). Recommended Practices for Design and Specification of Gearboxes for Wind Turbine Generator Systems. AGMA/AWEA 921-A97
2. ANSI/AGMA/AWEA. (2003). Standard for Design and Specification of Gearboxes for Wind Turbines. ANSI/AGMA/AWEA 6006-A03
3. IEC. (2012). Wind turbines - Part 4: Design requirements for wind turbine gearboxes. IEC standard 61400-4:2012
4. McNiff, B., Errichello, R., (1997) New guidelines promise reliable wind-Turbine gearboxes: What they mandate. http://www.machinedesign.com/Sustainable-Engineering/New-Guidelines-Promise-Reliable-Wind-Turbine-Gearboxes-What-They-Mandate. [Accessed 8 Dec. 2017].
5. McNiff, B., Musial, W., Errichello, R., (1990) Variations in Fatigue Life for Different Wind Turbine Braking Strategies SERI/TP-257-3984. Available at: https://www.nrel.gov/docs/legosti/old/3984.pdf [Accessed 8 Dec. 2017].
6. Nappi, G., Introduction of the new gearbox design standard for wind turbine generators: a gap analysis between IEC 61400-4 and ISO 81400-4 http://proceedings.ewea.org/annual2014/conference/posters/PO_036_EWEApresentation2014.pdf
7. Oyague, F. (2009). Gearbox Modeling and Load Simulation of a Baseline 750-kW Wind Turbine Using State-of-the-Art Simulation Codes. [online] Nrel.gov. Available at: https://www.nrel.gov/docs/fy09osti/41160.pdf [Accessed 8 Dec. 2017].

Paul Baker is vice president of Sales and Engineering for AeroTorque. He joined PT Tech/AeroTorque in February 2016 and has been working in the wind industry since June of 2004 with Moventas and Frontier Pro Services. Baker's diverse background includes the sales, repair, and application engineering of industrial and wind-turbine drives for the past 23 years. He has studied drive-train failures, written papers, and presented at AWEA, CanWEA, AGMA, and the national labs. A graduate of the U.S. Navy Nuclear Power Program, he completed undergraduate work at the University of Wisconsin and Arizona State University. He has served on working groups with AWEA, CanWEA, and AGMA.

Doug Herr is vice president of Sales and Marketing for AeroTorque. He joined PT Tech/AeroTorque in 2007 and has 20 years of industrial drivetrain experience. He began working in the wind industry in 2009, and he was deeply involved in the launch of AeroTorque. His early experience in the wind industry included significant up-tower work and monitoring of wind-turbine drivetrains, working to further develop the unique equipment AeroTorque uses for field data acquisition and field validation of the WindTC torque control. He has had papers published in numerous international industry magazines and has presented at conferences in the U.S. and Canada on the subjects of transient loads, their causes, and how they can reduce drivetrain reliability. He is a graduate of Juniata College.

Changing Turbine Gearbox Oil

Technology automatically changes oil in a fraction of the time it would take with traditional methods.

GlobeCore GmbH has developed the CMM-G unit for double-stage (old oil drain and new oil input) and triple-stage (old oil drain, gearbox flushing, and new oil input) automatic oil change. (Courtesy: GlobeCore GmbH)

By Frank May

Wind turbines remain a significant component of alternative electricity generation. The traditional design of such turbines includes a rotor, a generator, and a gearbox, which converts rotation of the rotor into generator-shaft rotation.

Although a different design of the wind-power units was developed in the 1990s with synchronous generators and frequency converters without the need to use gearboxes, most current wind turbines are equipped with them. Practical experience of operation indicates correct maintenance ensures full compliance with reliability and service life duration requirements.

POINTS OF ATTENTION

The technology of gearbox manufacturing has changed in the last decades due to growing loads and power. At the same time, the amount of oil used in generators to reduce friction, corrosion, and surface damage has been decreased.

Small wind turbines are equipped with gearboxes with a lifetime load of oil. If such devices break, they are not repaired, but replaced with new ones.

Large gearboxes come under extreme loads, wide temperature variations, variable wind speed, vibration, and moisture. The results are micropitting and breaking of meshed teeth and bearings. To prevent this, gearbox oil must perform its function well. It is the quality of the lubrication material (purity and high temperature stability) that is the decisive factor for long and reliable operation of a gearbox. This means the oil quality monitoring and timely oil change is a must.

WIND TURBINE GEARBOX OIL CHANGERS

As recently as 15 to 20 years ago the oil was changed

The technology of gearbox manufacturing has changed in the last decades due to growing loads and power. (Courtesy: GlobeCore GmbH)

by a human chain with buckets of oil. Some companies still rely on this method even now. However, it is hardly viable. First, manual labor is time consuming. Second, a simple oil change does not solve the problem since most contaminants remain in the gearbox after the change and quickly contaminate new oil.

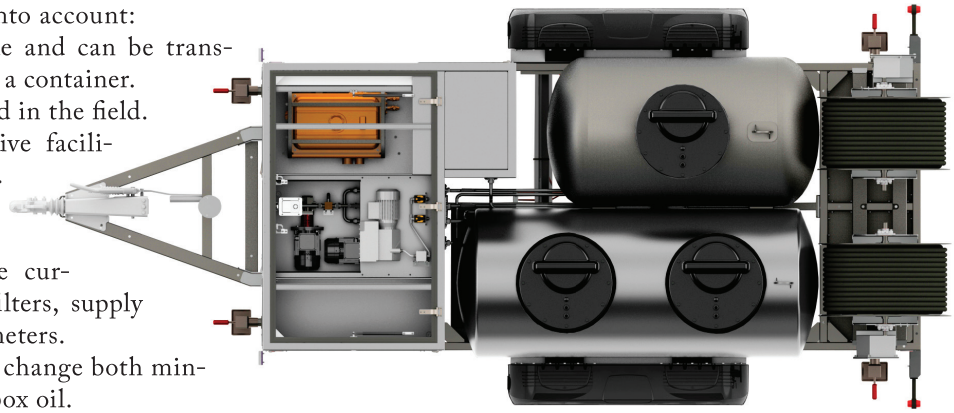
GlobeCore GmbH has developed the CMM-G unit for double-stage (old oil drain and new oil input) and triple-stage (old oil drain, gearbox flushing, and new oil input) automatic oil change. The unit can heat and filter new oil before filling the gearbox. The CMM-G unit takes the specific conditions of wind-turbine operation into account:

- The unit is fully mobile and can be transported on trailer and in a container.
- The unit can be operated in the field.
- A special electrical drive facilitates quick hose reeling.
- The control system manages flow setting depending on the current condition of the filters, supply height, and other parameters.
- The unit can be used to change both mineral and synthetic gearbox oil.

It takes two technicians more than 12 hours to change 80 gallons of oil, while the CMM-G unit can perform the same task in one to two hours. For small-scale renewable energy companies or small businesses servicing wind turbines, GlobeCore produces a small oil changer with independent tanks. A small model optimizes costs for servicing wind turbines.

No less important is the issue of frequency of wind-turbine gearbox oil change. There are two approaches: One takes into account the recommendations of the manufacturer regarding lubrication material lifetime, and the change is performed strictly in cycles (usually once every two or three years). The other approach involves assessment of the oil's quality and making a decision regarding oil change only after an analysis of oil samples.

The development of change schedule and selection of equipment for oil change is a complicated task that requires individual approach, depending on conditions (available equipment, the number of wind turbines to service, availability of specialists with practical experience in oil choice, and oil change). It is worth remembering, however, that only technological innovations can reduce both capital and operating costs.



The CMM-G unit can change the oil in a turbine in one to two hours. (Courtesy: GlobeCore GmbH)

Frank May is a service engineer at GlobeCore GmbH (Oldenburg, Germany). May has 30 years of practical experience in commissioning and servicing various oil-immersed and oil-processing equipment. For more information, go to globecore.com.