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Anatomy of a Component Upgrade

A systematic view of a wind turbine can offer benefits.

By Paul Baker and Doug Herr

As turbines come out of warranty, turbine owners absorb the costs of failed components but they also gain an opportunity to make reliability and power improvements.

Component upgrades that owners often face include bearings, lubrication, cooling and filtration, condition monitoring, power increases, and load control. A systematic view of the turbine can often benefit owners, as cumulative benefits can be linked to the whole of these upgrades. Here's a brief overview of what to expect when upgrading some of a turbine's more common areas:

BEARINGS

Bearings are a common upgrade opportunity owners often choose as their turbines come out of warranty. New designs, configurations, materials, and coatings will extend life to the system by increasing fatigue strength and durability. The choice should not be limited to the lowest cost provider. The bearings and the installation should always be an upgrade.

Downtime and lost revenue from a future repair always will cost far more than improvements made now with an experienced, competent crew. Specific to up-tower repairs, always consider replacing all bearings on a shaft rather than the broken one. Experience has shown replacing only one often leads to a re-repair in a short period of time. The small cost "saved" now can lead to significant damage and cost down the line.

LUBRICATION

One category under constant development is lubricating oils and greases. While polyalphaolefin (PAO) oils are predominately used as gearbox lubricating oils, each brand is designed differently, and each claim superiority. Important factors to consider are viscosity stability, resistance to foaming, corrosion resistance, and filterability. One strategy an owner might consider is to only evaluate OEM approved oils, as this approval is exceedingly difficult to obtain.

If you plan to change from one oil to another, you must budget for flushing as virtually no oils are compatible. Studies have shown cross-contamination can lead to significant problems down the road.

One counterintuitive consideration: You should not change oil based on gearbox condition. For example, AeroTorque has seen some owners change oil in a gearbox because of increasing iron counts in the oil samples or reported from on-line debris monitors. This is a gearbox problem, and while changing the oil may somewhat extend the life of the gearbox, it is financially unwise.

If the condition of the oil is otherwise within tolerance (viscosity, TAN, etc.), you will save money by filtering the oil with the use of an off-line filtration unit. Off-line filtration can often be moved from turbine to turbine. You must consider the damage in the gearbox already has occurred and will continue to produce the contaminants in the new oil.

Address the reason the gearbox is making metal as a gearbox failure, not an oil failure.

A GE gearbox in the field. A major corrective can be painful, but it is also an opportunity that should not be missed to help prevent future damage to components. (Courtesy: AeroTorque)

COOLING AND FILTRATION

When installing a brand-new or rebuilt gearbox, reviewing the performance of your cooling and filtration systems is a great idea. You should never attach an old cooler to a new box. When the system starts, you will immediately age that new box prematurely, as it is subjected to everything that has been sitting in the old cooler. Money saved on keeping the old system will be quickly lost by damaging the gearbox. Filter elements and systems are similar — as replacing them during a change-out is always cheaper than after the fact — with a now worn gearbox.

Some owners choose finer filtration that typically reduces particle counts,

ALSO IN THIS SECTION

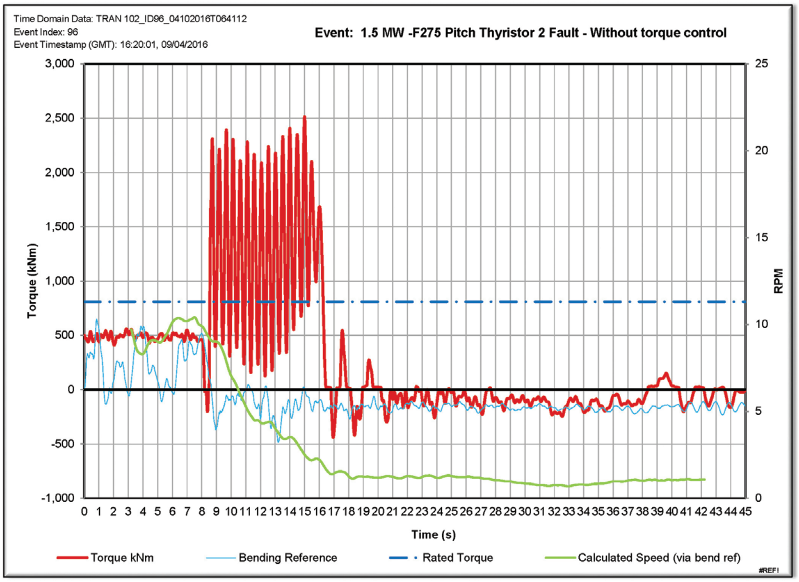


Figure 1: Actual field data of the high oscillations and intense torsional reversals that occur in wind turbine drivetrains. The blue dashed line is the normal operating torque, and the red line is the actual torque running through the drivetrain. (Courtesy: AeroTorque)

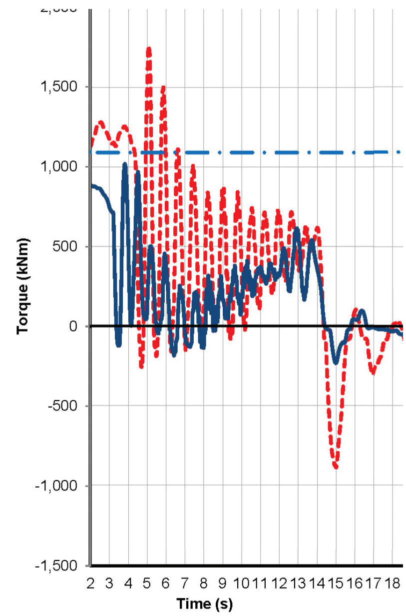


Figure 2: A torque plot from a different brand of turbine with (in blue) and without torsional load control (red). Reducing the loads can add significant life to components by eliminating torque spikes. (Courtesy: AeroTorque)

however you must ensure against excessive pressure drop across the filter. Larger filter elements are often available with additional debris capacity to extend filter-change frequency. Offline filtration is a more expensive upgrade but offers much finer filtration without concern of pressure drop, and in some cases the ability to remove water from the oil. As mentioned previously, these are available as permanently installed and portable units that can be moved from turbine to turbine.

CONDITION MONITORING

Condition monitoring has been growing in the industry, as owners have learned catching damage earlier can allow for repairs before excessive damage can occur. Additionally, a CM system can alert the owner to when he has to move to additional maintenance to deal with the increased particulates and oil conditions caused by the damage. Again, installing this while doing a major corrective is the best time to improve the overall system.

The two technologies that dominate the landscape are remote vibration analysis and remote on-line oil debris analysis. Both types of systems have their positives and negatives, and choosing the best system for your needs is often based on your team's experience and abilities.

Which technology provides earlier detection is debatable. Remote debris monitoring is much less expensive, but it does not provide the location of the damage as vibration analysis does. Laboratory oil analysis is also popular, especially to understand the condition of the oil. Route-based vibration analysis is popular for fleets that do not have installed capabilities but lacks the continuous sampling and up-to-the-minute information.

PRODUCTION IMPROVEMENTS

Production improvements come in two forms: incremental upgrades to existing equipment and "repowering." This will summarize the former, as "repowering" is generally a new means to qualify for PTC under the tax code rather than an asset management tool.

In a modern repowering, an owner works with an OEM to replace all of the components of the turbine except the tower and base. When finished, the owner is now back to an OEM warranty on the major components and will not be able to improve the system until that expires. Again, this is more of a financial tool than an O&M strategy.

The first true production improvements introduced to the industry were focused on capturing additional energy either through the use of vortex generators (VGs) or light detection and ranging (LIDAR). Vortex generators are an aerodynamic improvement that uses inexpensive plastic tabs that adhere to the turbine blades. These are generally designed for a specific turbine/blade combination and may result in greater than 1 percent additional energy capture.

Some experts believe a site specific design would result in even better improvement, although at additional engineering expense. LIDAR is a technology designed to measure changes in the wind before reaching the turbine, thus allowing the turbine to react and yaw and/or pitch in anticipation of the measured change.

LIDAR can be turbine specific, site specific, or something in-between.

The most prolific production improvements today are done by the turbine manufacturers themselves. These don't normally include increasing blade diameters, but in some cases it will in order to capture lower-than-expected wind speeds. These definitely include major changes to turbine-control systems, whose codes are held in strict confidence for obvious reasons. Most systems tap into "available margins" allowing the turbine to produce at its full potential. Some extend cut-in and/or cut-out speeds; others will simply allow for more aggressive blade-pitch angles, while some include aerodynamic improvements such as VGs.

All claim to better integrate SCADA data into a more proactive information loop. Naturally the concern with any production improvement is its impact to design-life and maintenance cost versus realized revenue increases. There is always a tradeoff between loading and life, so there is a higher likelihood of more damage to components if they are now subjected to new loading outside of the original design window.

LOAD CONTROL

To improve the performance of the entire system, as well as these upgraded components, something must be done to limit the excessive torque loads that caused the original damage. The research and the industry are

A major corrective, such as a gearbox replacement, offers an opportunity to extend life the second time around by introducing upgrades into the system. (Courtesy: AeroTorque)

coming to a consensus that normal operating loads are not the cause of significant damage. It is the torsional loads that are transient in nature, occurring far more than expected, that are causing the majority of damage.

These loads, which can be three times the normal operating torque, occur rapidly and are not captured by SCADA systems. The graph at right shows the significant oscillations and torsional reversals that can regularly occur in your turbine's drivetrain.

If you can reduce the transient loading in the drivetrain, all of the other O&M improvements can be more effective. As an example, if the original bearings lasted five years, improved bearings might last eight. With improved cooling, cleaner oil, and an improved additive base, they might last 10. If a load control is included that minimizes the impact of transient loads, then the system's life will dramatically increase, lasting 12 years or even more. This strategy not only helps pay for the costs of improvements, but it also removes much of the risk.

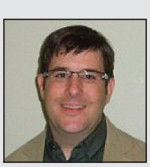
REAL-WORLD RESULTS

AeroTorque has seen these kinds of results first hand. When torsional load controllers were installed on new gearboxes on NEG/Micon NM-48-750, the effect was dramatic. With improved bearing and gearboxes installed at the same time as load controls, gearboxes failing in as little as three years saw little wear and no damage at all at that three-year mark. Conservatively, the owner estimated that he gained one to two years before any wear was seen. Since that time, multi-MW machines continue to see life improvements from adding torsional control to their drivetrains when they do major correctives.

Component choices are made for budgetary reasons, as well as life. However, when considering costs, a wider scope is needed: Operational costs such as downtime and other factors should be included in calculations in order to understand true costs and value.

Better component options, load control solutions, and other improvements mean owners do not have to accept higher failure rates and increased O&M costs. By making these choices earlier in a turbine's life, you can control the second half of your turbine's life and make it more profitable as it ages. Only through a system-based solution can you truly gain control of your future costs.

Doug Herr joined PT Tech/AeroTorque in 2007 and has 18 years of industrial experience. He began working in the wind industry in 2009 and was involved in the launch of AeroTorque when it was spun out of PT Tech in 2013. His early experience in the wind industry included significant up-tower work and monitoring of wind-turbine drivetrains, working to further develop the equipment AeroTorque uses for field data acquisition and field validation of the WindTC torsional control.



Paul Baker joined AeroTorque in February 2016, and has worked in the wind industry since June 2004 with Moventas & Frontier Pro Services. Baker's background includes sales, repair, and application engineering of industrial and wind-turbine drives for the past 22 years. He has studied drivetrain failures, written papers, and has 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.

Keeping Tabs on Parts and Systems

Monitoring vibrations from shipping through the lifespan of a turbine is an effective way to prevent costly downtime.

By Paula Simoes

Vibration monitoring is one of the most effective indicators of operational issues and the need for preventative maintenance in wind power. (Courtesy: ShockWatch)

To avoid the need for costly repair or even replacement, sophisticated equipment in any industry should be accurately monitored and observed to identify maintenance needs before they escalate into true problems or equipment failures.

Vibration monitoring is one of the most effective indicators of operational issues and the need for preventative maintenance in wind power, offering a snapshot of any current issues, as well as what may arise in the future.

Real-time vibration condition monitoring allows users to prevent downtime for their systems, maximize utilization, and protect their equipment in real time — both before and after installation — ultimately reducing the cost of operation and improving efficiency across the board.

Importantly, a monitoring system with a user-friendly interface that does not require a new subset of tasks or skills will not only improve the way companies can operate moving forward, it will enable them to also maximize the potential of their current configuration. Studies have shown having an active and practical condition monitoring system results in a more efficiently operated power-plant system.

PREVENTATIVE MAINTENANCE

When is the best time to fix a problem? Before it ever occurs. The possibility of installing faulty or worn components can cause untold damage to a company's systems, other equipment, and its bottom line. Without a preventative maintenance program in place, wind-power companies place themselves at much greater risk of incurring unnecessary costs.

If companies can observe and audit the status of equipment before their personnel can lay a hand on it for installation, by default, costs are reduced, and productivity is increased. Through the accurate and timely monitoring of a particular variable, such as vibration, over the lifespan of the materials, companies can effectively keep tabs on their wind systems from the first day of transport through the day it is disassembled.

By measuring both impact and low-frequency vibration, engineers can easily identify machine deterioration during operation. However, it is also important to allow users to detect potential shipping damage on a product before it is installed. This protects equipment, prevents unplanned downtime, maximizes utilization, and reduces the cost of operation.

By monitoring equipment vibration during transportation and capturing impact alerts and data, a truly effective monitoring system provides warning of potential damage to equipment before it is installed. The impact-monitoring profile of a piece of equipment changes when it is being transported as a component versus when it becomes part of a larger operational system, so being able to adjust the settings of a single monitoring system to correlate to the equipment's arrangement provides users the ability to monitor their equipment effectively throughout the journey.

SPEED AND ACCURACY

Once equipment is operational, effective monitoring programs rely upon accurate data and timely alerts to any change or irregularity in that data. Ideally, service and maintenance team members are alerted electronically through email or text alerts when there is a change to the vibration data that signifies a potential issue. That team can then perform the analysis required to determine maintenance or component replacement needs before a failure occurs.

Vibration and shock monitoring is an integral part of machine condition-monitoring programs. Change in equipment vibration serves as an early warning of a decline in operating function, and it signals the need for maintenance to avoid more serious faults and/or failure. All equipment that has belts, gears, bearings, drive motors, and other moving components has a "normal" range of vibration during operating cycles. Any system comparison of vibration data must use a starting point, or normal range, to record peaks and valleys in vibration, should they exist.

This "normal" range is then monitored at a baseline level and sets a range for regular performance from which the smallest, and more significant, changes may be detected. The shocks and normal wear-and-tear of usage that equipment experiences over time generate changes in vibration pattern.

By establishing these "normal" ranges on various pieces of equipment, a condition-monitoring system can differentiate which impact and vibration levels are of concern based on the particular profiles.

REAL-TIME OBSERVATION

An effective monitoring system will enable real-time observation of low-frequency shock and vibration to identify these changes as they happen. If the system perceives vibration outside the normal range, it will provide an alert to the user, helping to identify potential equipment faults before they occur.

Through the use of detailed and specific profiles that monitor the day-to-day operation of users' equipment in stationary mode, first-rate monitoring systems allow companies to use low-frequency vibration and shock detection to drive preventative maintenance before expensive repairs or even equipment replacement is required. Regardless of industry, maximizing utilization and effective resource management is a tent-pole strategy of successful operations.

Some vibration-monitoring system software can be easily configured to meet a company's specific needs. In transportation or stationary mode, the user sets impact-event maximum peak values (on the X, Y, and Z axes) with a subsequent warning and alarms levels based on the specific application and the product being monitored. Systems that can be customized specifically to a user's existing system when requested ease the headaches of a transition in new equipment or vibration monitoring system installation.

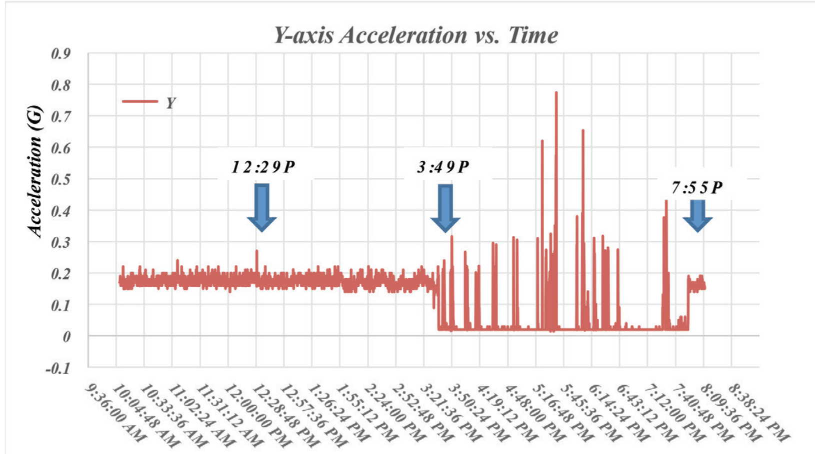


Figure 1: At 12:29 p.m., an acceleration spike occurred. By 3:49 p.m., vibration readings increased indicating machine failure. The machine returned to regular performance at 7:55 p.m. (Courtesy: ShockWatch)

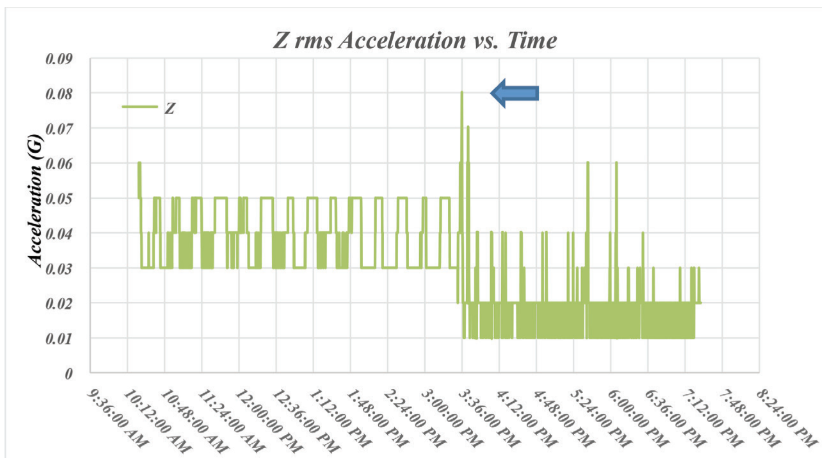


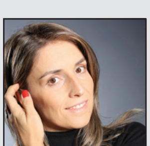
Figure 2: Viewing the same machine failure shown in Figure 1, but with RMS values. The overload took place at 3:35 p.m., which was 14 minutes before failure. (Courtesy: ShockWatch)

POWERFUL AND COMPACT

While imbued with immense power, the monitoring unit should also ideally be compact enough to perform its tasks without requiring excess space or weight adjustments and be able to withstand a wide temperature range while remaining viable in extreme conditions during both transport and use. With the prescribed ranges for operation and vibration detection defined, intelligent condition-monitoring systems can then adjust reporting structures and frequency as external factors allow.

When used during transportation, an effective monitoring system will allow the user to record vibration events tracked against preset, acceptable ranges — as well as the necessary warnings and alerts — are defined. In the same device, while employed in stationary use, the user could record an almost limitless number of events that raise alarms and prompt any necessary action.

An effective, state-of-the-art vibration monitoring system combines all these elements in a single easy-to-use, customizable, powerful and compact device. OpsWatch, from ShockWatch, sets an industry standard in measuring both impact and low-frequency vibration to identify machine deterioration during operation and detects potential shipping damage to protect equipment, prevent unplanned downtime, maximize utilization, and reduce the cost — making it an invaluable asset to leaders in the wind-power industry.



Paula Simoes is the vice president of IoT Portfolio & Technology at ShockWatch. She has 18 years of international experience in the ICT world and has led operations and engineering teams for companies such as Vodafone and Orange Portugal. Over the past seven years, Simoes has held several strategy and business leadership roles in the Internet of Things (IoT) space, most recently as the vice president of Product and Partnerships in a Dallas-based IT company developing IoT software platforms.

Diagnosing Wear Faults

High-throughput screening of wind-turbine gearbox samples using the LaserNet 230 and automatic sample processor (ASP).

By Tom Barraclough

The major issue for premature failure in wind-turbine gearboxes is bearing failure, which leads to gearbox failure. A wind-turbine gearbox will not survive if the oil is not clean and especially if the hard ferrous particles are not removed from around the bearings.1

The LaserNet 230 particle counter and ferrous debris monitor has been shown to be an excellent analytical tool for end users to diagnose wear faults in various machine applications such as gearboxes, engines, and transmissions. The wear generated in a wind-turbine gearbox is a function of load, speed, and lubricant condition. The lubricant must be correctly specified for the turbine gearbox's idealized operating load and speed, and its condition must be carefully monitored in order to maintain the required lubricant film thickness in these regimes.

The wear generated in a wind-turbine gearbox is a function of load, speed, and lubricant condition. (Courtesy: Spectro Scientific, Inc.)

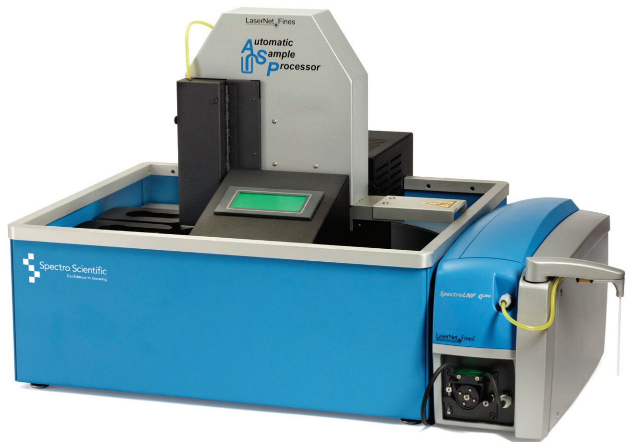
Ever-changing wind conditions and large variations in climates make wind-turbine condition monitoring extremely challenging. As a result, careful continuous automated monitoring of these critical and expensive assets is required. The National Renewable Energy Laboratory (NREL) uses the Lasernet Fines (LNF) technology in drive-train wind-turbine monitoring. It has demonstrated and recommended that condition-monitoring using the LNF is critical to avoiding premature failures in wind turbines.2

Existing particle counter/auto sampler setups are not ideally suited for processing heavy batches of wind-turbine oil samples that also can vary considerably in contamination level. Extra dilution steps for the viscosity and the contamination levels are required, making them unsuitable compared to the standard clean oil hydraulic applications they were initially designed for.

GEARBOX WEAR PARTICLES

The abnormal wear generated in any gear system typically comes from the pitch line of the gear tooth (fatigue) or the tip of the gear (severe sliding). At the pitch line, the contact is rolling, so the particles will be similar to rolling contact fatigue particles. The gear contact has an increased sliding component as the root or tip is approached, and the particles will show signs of sliding morphology.

This morphological wear data is extremely beneficial to the end user, and abnormalities in the gearboxes caused by large particle generation are easily identifiable when trends are established that can distinguish ferrous from non-ferrous material. Another critical feature of a wind-turbine gearbox is the bearings are both on the low- and high-speed stages, and any misalignment of these will induce failure.



Spectro Scientific ASP, a self-contained sample changer and processor designed for use with the LaserNet 200 Series. (Courtesy: Spectro Scientific, Inc.)

ASP SYSTEM ADVANTAGES

- Output of high-quality, condition-based wear metrics, size distributions, wear shape classification, ppm ferrous, ferrous versus non-ferrous particles.
- Screening for ferrography and further root cause analysis tests becomes easier.
- Continuous operation over a wide range of contamination levels from 1,000 parts per milliliter to greater than 2 million parts per milliliter
- No batch processing based on sample cleanliness is necessary due to the dynamic/intelligent flush capability that prevents carryover.
- Ability to analyze and screen more than 100 samples a day without dilution or sample preparation.
- Superior sample homogenization compared to shaking using vortex stirring method.

HIGH THROUGHPUT

Online techniques are offered as site solutions for customers with multiple windfarms, but these are costly and not sensitive enough. Centralizing the testing analysis by sending samples to a regional service center offers the best cost to monitoring benefit when large volumes of turbine samples are involved. Contract labs with the right high-throughput screening tools are well-equipped to turn around data quickly and can recommend further action and/or testing if necessary.

In a high sample-throughput scenario, such as a contract lab running more than 100 samples per day, it's important to be able to screen samples accurately so a more thorough and in-depth ferrography analysis can be done on those select samples that show abnormal LNF/ferrous readings.

Ferrography is still one of the leading root-cause analysis techniques, but it requires a complimentary screening methodology that closely links particle size distributions, morphology, and ferrous content.

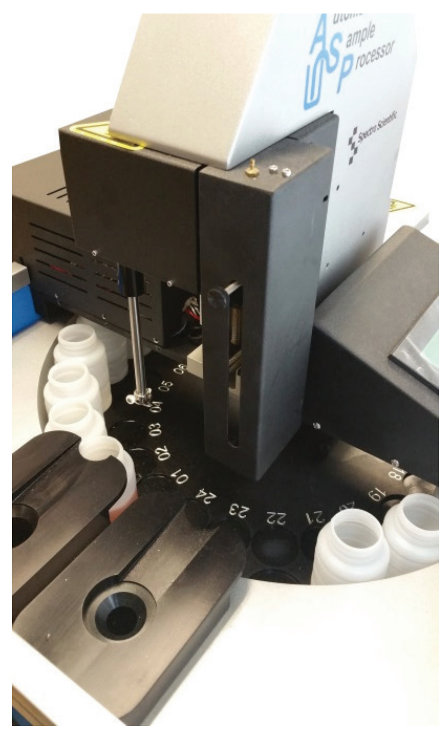
LASERNET 230 AND ASP COMBINATION

By coupling a fully equipped LaserNet 230 with ferrous capability to an automatic sample processor (ASP), a full tray of 24 heavy (320cSt) wind-turbine gear-oil samples can be analyzed in about 2 1/2 hours. This continuous operation includes sample preparation and system cleaning. This all can be accomplished with no operator intervention and can yield the following results:

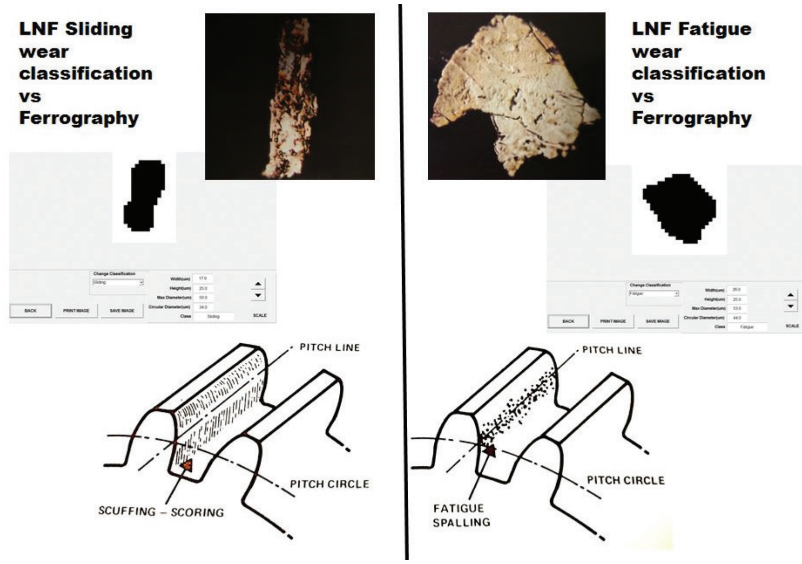
- Particle distribution greater than 4um (ISO 4,6,14 Codes)
- Wear Shape classification and distribution greater than 20um (p/ml)
- Percentage of large ferrous greater than 20um (p/ml)
- Total ferrous (ppm)
- Free water (Additional information on free water contamination present in the gearbox can also be reported from the water droplet classification.)

ANALYZING HEAVY GEARBOX OILS

The ASP has been uniquely designed to complement the LaserNet 230 by using stir-and-wash sequences used to simulate the typical manual sample preparation steps like shaking and rinsing during routine LNF analysis.



Sample head of an ASP showing stirrer, sipper tube, and solvent tanks. (Courtesy: Spectro Scientific, Inc.)



Examples of sliding wear and fatigue wear generated in a gear system. (Courtesy: Wear Particle Atlas, Predict Technologies)

The particles in the sample are homogenized using a special stir motor that rotates at an optimally selected speed. The stirring creates a vortex effect in the oil that sucks the particles from the bottom of the bottle and into the sample volume creating a homogenized sample. The speed is selected so as not to introduce excessive bubbles into the sample (the LaserNet 230 easily classifies bubbles greater than 20um and does not count them).

The stirring method using the ASP is ideally suited for heavy gear oils compared to manual shaking on a standalone system. The viscous forces of the heavy oil make manual shaking and homogenization of the particles impossible. The remaining bubbles left in the bottle also take a much longer time to be removed by vacuum degassing or ultrasonic methods.

Once the sample has been stirred, the contamination on the stirrer and sipper are cleaned using solvent spray jets in the wash tanks. The stirrer is then spin dried, so it will be ready for the next sample.

By running samples in this exact same mechanical manner over and over, the repeatability from sample to sample is excellent, and any deviation in sample data from a well-established trend can easily be identified by an analyst.

Continuous operation of the ASP/LaserNet 230 system is important when dealing with hundreds of gearbox samples a day with various levels of wear and contamination. In a typical batch of wind-turbine gearbox samples, it's not uncommon to have high levels of water or additive breakdown often being reported as greater than 2 million particles. The LNF imaging system can easily handle such high levels of contamination without any issues, but it's important that the next sample is not cross-contaminated.

This is achieved by using a specially developed dynamic flush sequence that varies the amount of flushing required by continuously monitoring the particle count as the flush is taking place. A cleanliness threshold is set in the software, and once the count gets below this value, the flush stops, and the sample progresses. This is important as a typical wind-turbine gearbox running on a relatively new oil may only contain 1,300 to 10,000 parts per milliliter or an ISO code from 18 to 20. The incorporation of a bubble valve into the ASP flush line simulates a manual operator adding pockets of air shown to dramatically speed up flushing. It also removes excessive contamination quicker than a straight stream of solvent.

CONCLUSION

The ASP/LaserNet 230 ferrous combo is an ideal screening solution for wind-turbine gearbox applications where sample volumes are high. The system can accurately and repeatedly identify problem samples from a trend based on particle-size distributions. The source of the wear can be identified using the shape classifier and the ferrous information.

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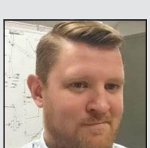

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