Understanding Oil Analysis: How It Can Improve Reliability of Wind Turbine Gearboxes

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Historically, wind turbine gearbox failures have plagued the industry. Yet an effective oil analysis program will increase the reliability and availability of your machinery, while minimizing maintenance costs associated with oil change-outs, labor, repairs and downtime. Practical action steps are presented here to improve reliability.

Introduction

Lubricating oil is the lifeblood of the gearbox. It is required to carry out specific functions in order to keep the gearbox running. In wind turbines, the lubricant is subjected to extreme temperatures, varying load weights and contamination. Lubricant performance deteriorates under these conditions, and thus oil analysis becomes essential to monitor lubricant condition.

Oil analysis is used extensively to help companies maintain their equipment. In order to take full benefit from the test data, it is important to understand the basic properties of a lubricant. Equally important is the understanding of how these properties affect the ability of the lubricant to function. Lastly, knowledge of the common test methods and instrumentation used to analyze oil will aid in data interpretation and lead to more productive corrective action. After gaining a fundamental understanding of lubrication, we will apply these fundamentals to wind turbine gearboxes to demonstrate the unique challenges inherent in this industry.

Lubricant Role

To effectively monitor how well a lubricant is functioning, you must first examine what the functions of the lubricant actually are. The primary function of a lubricant is quite obviously to *lubricate*. Lubrication can be defined as the reduction of friction. By reducing friction, wear is reduced, as is the amount of energy required to perform the work.

In 1699, the French physicist Guillaume Amontons (1663 – 1705) deduced that friction is the result of surface roughness. Since no solid surface is perfectly smooth, opposing friction surfaces have peaks — "asperities" — that come in contact with one another. Ideally, a lubricant will physically separate these asperities with an oil film; this is called "full-fluid" film lubrication (Fig. 1).

When the proper lubricant is used, and the proper load is applied, the asperities are not in contact and, in theory, no wear will occur. But when inadequate lubrication is present, or the load is increased, the oil film will not be thick enough to fully separate the asperities. "Mixed lubrication" — a cross between boundary and hydrodynamic lubrication — occurs when the oil film thickness is equal to the average asperity height. The largest asperities will come in contact, resulting in increased wear.

Many oils are fortified with anti-wear additives to combat wear under these circumstances. As load continues to increase, or lubrication degrades, boundary lubrication occurs and the oil film thickness cannot separate the friction surfaces. This can result in metal-to-metal contact. At this point, asperities are adhering to one another, causing severe machine wear. This can also manifest itself during periods of shock loading, start-up or shutdown. Extreme pressure additives are used in oils that frequently encounter these types of situations.

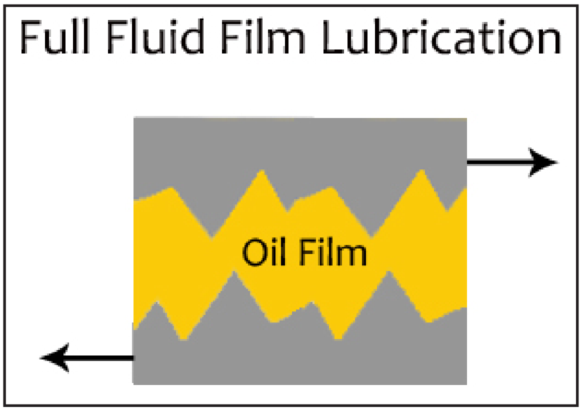
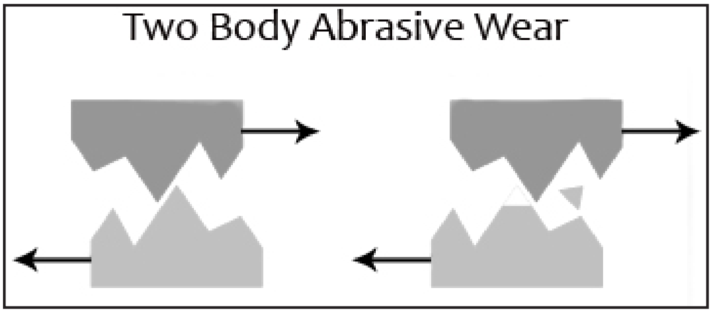
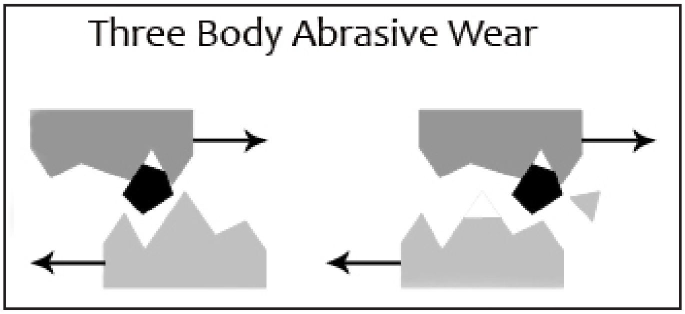


Figure 1 Friction is the result of surface roughness — asperities — that come in contact with one another. Full-fluid film lubrication will physically separate these asperities.





Lubricants are also tasked with controlling the temperature of your equipment. Oil absorbs heat generated at the friction surface and carries it away to be dispersed. Many systems incorporate heat exchangers or radiators to aid in removing heat from the system. Along with heat, lubricants transport dirt and other debris away from the friction surface.

Particulate contamination leads to increased wear through abrasion and reduced oil flow. Some oil additive packages contain agents that break contaminants up and hold them in suspension to be filtered out or settle in the reservoir. This prevents harmful deposits and varnishes from forming within the equipment. Alkaline additives also protect the components by neutralizing acids and preventing corrosion.

Hydraulic oils have the added function of transmitting power. To function properly, hydraulic oil must be clean and free of contaminants. Many contaminants will cause oil to foam and entrain air or water. Entrained air causes the oil to compress under pressure, resulting in a loss of power. Particulate contaminants will cause valves to malfunction and restrict the oil flow.

Role of Oil Analysis

Selecting the proper lubricant, along with careful maintenance of that lubricant, is essential to ensure adequate protection to any machine. Proper lubrication is defined as a correct amount of the correct lubricant at the correct time.

Maintaining your lubricants means ensuring that you are using the correct viscosity and have the necessary additives for the application. You must also take steps to keep the lubricant clean and serviceable. Bottom line — oil analysis is the most effective way to prolong the useful life of your lubricants while maintaining maximum protection of your equipment.

Oil analysis tests reveal information that can be broken down into three categories:

1. ***Lubricant condition***. Assessment of the lubricant condition reveals whether the system fluid is healthy and fit for further service, or is ready for a change.
2. ***Contaminants***. Increased contaminants from the surrounding environment in the form of dirt, water and process contamination are the leading cause of premature machine degradation and failure. Increased contamination alerts you to take action in order to save the oil and avoid unnecessary machine wear.
3. ***Machine wear.*** An unhealthy machine generates wear particles at an exponential rate. The detection and analysis of these particles assist in making critical maintenance decisions. Machine failure due to worn out components can be avoided. Remember — healthy and clean oil lead to the minimization of machine wear.

Lubricant condition is monitored with tests that quantify the physical properties of the oil to ensure that it is serviceable. Metals and debris associated with component wear are measured to monitor equipment health. Lastly, some tests target specific contaminants that are commonly found in oils. It is imperative to select the proper blend of tests to monitor the machine's lubricant condition, wear debris and contaminants in order to meet the goals of successful oil analysis.

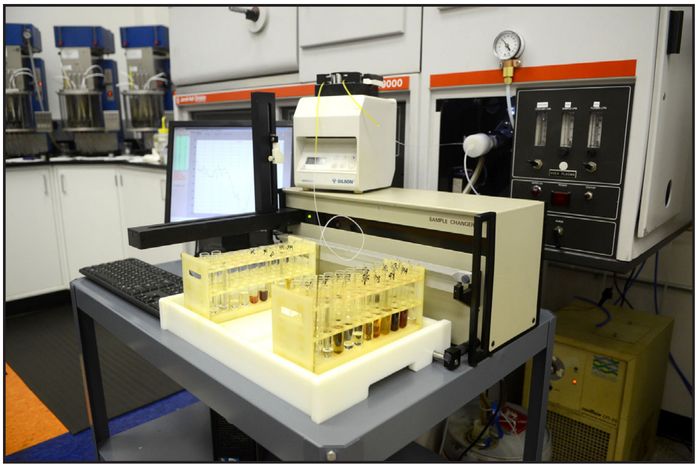


Figure 2 **There are typically 20 elements measured by spectroscopy and reported in parts per million (ppm).**

Elemental Spectroscopy

Elemental spectroscopy is a test that has the distinction of monitoring all three categories — lubricant condition, wear debris and contaminants. A spectrometer is used to measure the levels of specific chemical elements present in an oil.

Two types of spectrometers are commonly used. Arc emission spectrometers apply energy in the form of an electric arc to the sample. This excites the atoms into vapor form, creating a spectrum where light is generated. Individual light frequencies in the spectrum are measured and quantified to determine the presence and quantities of specific elements present. The other common type of spectrometer is the ICP (inductively coupled plasma) spectrometer. This operates on a similar principle, except that the energy is applied to the sample by a plasma flame rather than an electric arc.

There are typically 20 elements measured by spectroscopy and reported in parts-per-million (ppm) (Fig. 2). These measurements represent elements in solution. Spectroscopy is not able to measure solid particles larger than roughly seven μm, which leaves this test blind to larger solid particles.

Typical levels of wear can vary greatly, depending on the type of equipment being sampled. For example, a gearbox will normally have much higher levels of iron than a hydraulic system. Levels of wear metals can vary across different units of the same type, depending on oil hours, operating conditions and loading levels or other conditions. For this reason it is impossible to establish firm limits for any piece of equipment based solely on the equipment type. To take full advantage of monitoring wear, a trend should be established to provide an operational baseline of data. This will ensure detection of abnormal wear rates as they develop while allowing for the fact that similar equipment may not wear at the same rate.

Monitoring the additive levels provides information to ensure that the proper lubricant is being used for the application and for topping off. Four types of lubricants are generally used in most industrial applications, and each has different additive levels. It is important to note that an oil's level of additives measured by spectroscopy is not necessarily an indication of the oil's quality.

- ***Engine oils*** will typically contain anti-wear additives composed of zinc and phosphorus. One should expect to see these elements present in approximately 1,000 ppm (± 200 ppm). A detergent package should also be present, composed of some configuration of barium, magnesium and calcium. These levels will vary, depending on the oil.

- ***Extreme pressure oils*** are typically for gear applications. It is common to see significant amounts of phosphorus.
- ***Anti-wear oils*** include many bearing oils, some gear oils and hydraulic fluids. These oils contain both zinc and phosphorus from 200 to 600 ppm. There may be very low levels of detergent (magnesium or calcium) present also.
- ***Rust and oxidation inhibiting oils*** are the easiest to identify. They include turbine oils, compressor oil, and some bearing and hydraulic oils. These oils have no metallic additives that can be measured by spectroscopy, so there should be extremely low numbers for all additive metals.

It is not uncommon to see low levels (<20 ppm) of some additive metals where they are not expected. This is usually the result of residual contamination in the equipment or storage tanks. There are oils that do not fit into these descriptions. Many oils are formulated for specific applications and alternative additives must be used. An example would be oils formulated for some stationary and electro-motive diesel engines. In many cases, operating conditions or emission concerns call for a less traditional additive package.

As with any type of testing, spectroscopy is subject to inherent variance. High water levels can cause interference in the spectrum, as can the matrix of some synthetic base stocks. In short, always double-check with another sample before taking any invasive maintenance action. Never rely on just one piece of data when making a maintenance decision.

Viscosity

Viscosity is considered oil's most important property. The most common technique for measuring an oil's viscosity is following ASTM D445, using a viscometer (ASTM, 2011). A small sample of the oil is drawn into a calibrated capillary tube in a constant-temperature bath. Once the sample comes to temperature, it is allowed to flow down the tube a predetermined distance. The viscosity is the product of the flow time and tube calibration factor. The results are reported as the oil's kinematic viscosity in centistokes (cSt).

Industrial oils are identified by their ISO viscosity grade (ISO VG). The ISO VG refers to the oil's kinematic viscosity at 40°C (104°F). An oil's weight commonly refers to its kinematic viscosity at 100°C (212°F). The weight of multi-grade oils is represented by the second number in the rating. A 10W30 would be 30-weight oil. The 10 before the W, which stands for winter, refers to how the oil performs in cold weather conditions.

When an oil's viscosity increases, it is usually due to oxidation, degradation or contamination. This is the result of extended oil drain intervals, high operating temperatures, or the presence of water or another oxidation catalyst. Increased viscosity can also be the result of excessive contamination with solids such as soot or dirt, as well as topping off with a higher grade lube. Water contamination can also cause high viscosity.

A decrease in the oil's viscosity is most commonly due to contamination with fuel or a solvent. An oil's viscosity also can be affected if the wrong oil is used for top-off or replenishment.

Figure 3 If a lubricant does not have the proper viscosity, it cannot properly perform its functions.

If a lubricant does not have the proper viscosity, it cannot properly perform its functions (Fig. 3). If the viscosity is not correct for the load, the oil film cannot be established at the friction point. Heat and contamination are not carried away at the proper rates, and the oil cannot adequately protect the machine.

Acid Number

Acid number (AN) is an indicator of oil health. It is useful in monitoring acid buildup in oils due to depletion of antioxidants. Oil oxidation causes acidic byproducts to form. High acid levels can indicate excessive oil oxidation or depletion of the oil additives and can lead to corrosion of the internal components. By monitoring the acid level, the oil can be changed before any damage occurs (Fig. 4).

An oil analyst is looking for a sudden increase. When your oil is flagged for high acid levels, it indicates accelerated oil oxidation, and you should change the oil as soon as possible. If any of the remaining highly acidic oil is left, it will quickly deplete the antioxidants in the new oil.

Acid number is measured by titration using ASTM D664 or D974. Both methods involve diluting the oil sample and adding incremental amounts of an alkaline solution until a neutral endpoint is achieved.

Figure 4 By monitoring the acid level, the oil can be changed before any damage occurs; an oil analyst is looking for a sudden increase.

The acid number of a new oil will vary, dependent upon the base oil additive package. An R&O oil will usually have a very low AN, around 0.03. An AW or EP oil will have a slightly higher value, typically around 0.5. Engine oils commonly have a higher AN, in the neighborhood of 1.5.

Base Number

Base number testing is very similar to acid number testing except that the properties are reversed. The sample is titrated with an acidic solution to measure the oil's alkaline reserve. ASTM D2896 and ASTM D4739 are the most commonly used methods to measure the base number (ASTM, 2007; ASTM, 2008).

Many oils (especially motor oils) are fortified with alkaline additives to neutralize acids that are formed as a result of combustion. In diesel engine applications, acid is formed in the combustion chamber when moisture combines with sulfur under pressure. Measuring the base number will help ensure that a sufficient amount of additives have been added to the oil to help resist oxidation due to acid (Fig. 5).

The base number of oil is highest when the oil is new and decreases with use. Once again, condemning limits are based on the application. As a rule, the base number should not drop below half of its original value. Base number values for new engine oils very greatly depending on the application.

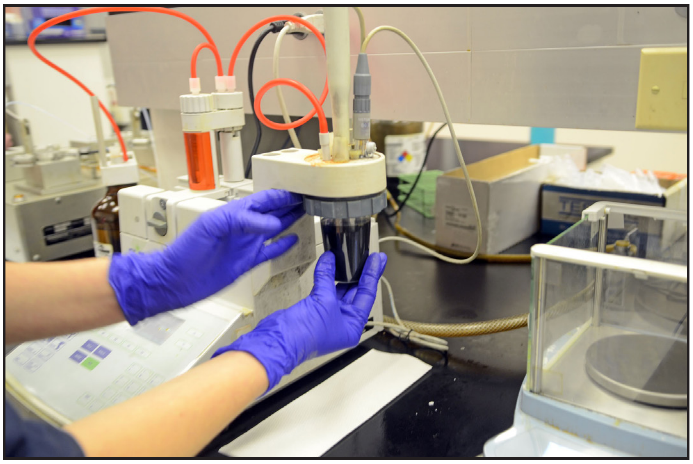


Figure 5 Measuring the base number will help ensure that a sufficient amount of additives have been added to the oil to help resist oxidation due to acid.

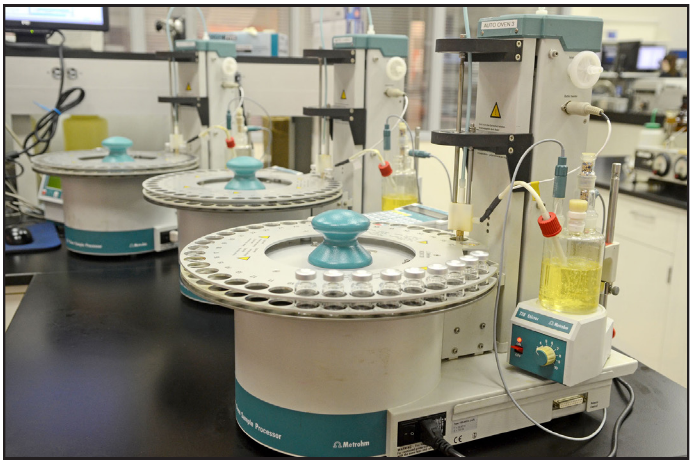


Figure 6 If a crackle test is positive, further testing is needed to quantify the amount of water by using Karl Fischer titration by ASTM D6304 (ASTM, 2007).

Water Contamination

Water contamination is detrimental to any lubricant. A simple crackle test is used to determine if water is present in oil. A small volume of the lubricant is dropped onto a hot plate and, if bubbles or crackles occur, water is present.

If a crackle test is positive, further testing is needed to quantify the amount of water by using Karl Fischer (*Ed.'s Note: German chemist, 1900–1958*) titration by ASTM D6304 (ASTM, 2007) (Fig. 6). A measured amount of oil is introduced into a titration chamber. This solution is titrated with Karl Fischer reagent to a specific end-point. The amount of reagent used and the sample volume are calculated and converted to ppm (percent by mass).

Low levels of water (<0.5%) are typically the result of condensation. Higher levels can indicate a source of water ingress. Water can enter a system through seals, breathers, hatches and fill caps. Internal leaks from heat exchangers and water jackets are other potential sources.

When free water (non-emulsified) is present in oil, it poses a serious threat to the equipment. Water is a very poor lubricant and promotes rust and corrosion to the components. Dissolved water in oil (emulsified) will promote oil oxidation and reduce the load handling ability of the oil. Water in any form will cause accelerated wear, increased friction, and high operating temperatures. If left unchecked, water will lead to premature machine failure. In most systems, water should not exceed 500 ppm.

Particle Count

Particulate contamination has negative effects on all types of equipment. Particle count testing is a way to monitor the level of solid contamination in the oil. Two types of automatic particle counters are used to test oil cleanliness: light blockage and pore blockage.

- ***Light blockage***: The light blockage technique involves passing a sample through a small orifice that has a laser light source on one side and an optical sensor on the other side. Particles interrupting the light beam are counted, and size is determined by the degree of light blockage. Light blockage particle counting is not effective when oil is contaminated with water or when air is entrained in the oil. In these circumstances, water or air bubbles will be counted as particles, causing erroneous results.
- ***Pore blockage***: The pore blockage or flow decay technique passes the sample through a mesh filter. As a filter clogs, the flow of the sample is slowed. The amount of flow decay is calculated, and the particle count can then be extrapolated. Because water droplets and entrained air will not restrict the fluid flow, there is no interference from these contaminants.

Results are reported as particles-per-milliliter in six size ranges: >4; >6; >14; >25; >50; and >100. ISO cleanliness codes are then assigned for particles in 4, 6 and 14 μm ranges (ISO 4406:1999). The result is reported by three numbers with a slash between them; the first number refers to particles in the >4 μm range; the second to particles in the >6 μm range; and the third in the >14 μm range. The lower the numbers in the ISO cleanliness code — ISO 4406 — the cleaner the fluid.

Figure 7 Particulate contamination is a measurement of the effectiveness of filtration and can indicate when excessive external contamination is occurring.

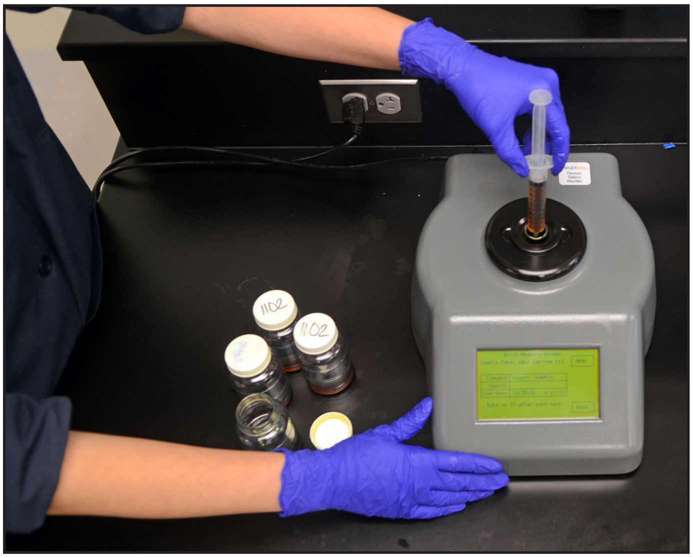


Figure 8 A wear particle analyzer quantifies the amount of ferrous material present in a sample of fluid.

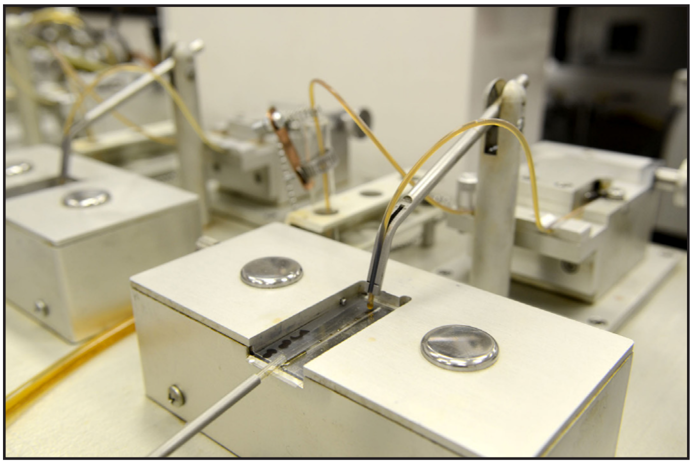


Figure 9 Analytical ferrography is able to identify wear particles, their composition and their origin by visually analyzing them microscopically.

Particulate contamination is a measurement of the effectiveness of filtration, and can indicate when excessive external contamination is occurring (Fig. 7). Advanced machine wear will also cause increased particle counts. Generally, the lower size ranges are considered indicative of contamination and silt, while the larger size ranges point to wear problems.

Ferrous Wear Concentration

In some cases a particle count is not an effective test because the sample is inherently dirty and filtering the oil may not be plausible. A particle count indicates that the sample is extremely dirty, but it does not give any indication of ferrous wear. In gearboxes, ferrous wear may be more important than overall particle count. In such an application, ferrous wear concentration is a good substitution for a particle count test.

A wear particle analyzer quantifies the amount of ferrous material present in a sample of fluid (Fig. 8). A measured amount of sample is inserted into the analyzer and amount of ferrous material is determined by a change in magnetic flux. This change is then converted into ferrous concentration in parts-per-million. Using this method, there are no interferences with non-ferrous particles.

One advantage of a ferrous debris monitor is that it will measure ferrous wear debris in all types of oil, from gearbox lubricants through hydraulics; another key benefit is that it will also measure ferrous wear debris found in grease.

A test similar to the ferrous debris monitor is DR (direct read) ferrography. DR ferrography collects positively charged particles on two light sources and measures the amount of blocked light to determine the level of ferrous contaminants present in an oil. Although these two tests provide the same information, they are not interchangeable.

Analytical Ferrography

Analytical ferrography is used to separate solid contamination and wear debris from a lubricant for microscopic evaluation. As stated earlier, spectroscopy is not able to measure wear particles larger than 7 μm in size. While particle counting, ferrous wear concentration and DR ferrography are able to detect the presence of larger particles, they cannot qualify their composition or origin. Analytical ferrography is able to identify wear particles, their composition and their origin by visually analyzing them microscopically (Fig. 9).

A diluted oil sample is allowed to flow over a specially treated slide positioned at an angle over a strong magnet. The ferrous (iron) particles are attracted to the magnet and deposited onto the slide in decreasing size as the oil flows down the substrate. Nonferrous particles are deposited randomly, while ferrous particles line up in chains as a result of the magnetic flux. The result is a microscopic slide with the particles separated by size and composition.

Microscopic examination of the debris reveals information about the condition of the equipment. Observing the concentration, size, shape, composition and condition of the particles indicates where and how they were generated. Particles are categorized based on these characteristics, and conclusions can be drawn regarding the wear rate and health of the machine.

The composition of the particles can be identified by color. Heat treating the slide causes specific color changes to occur in

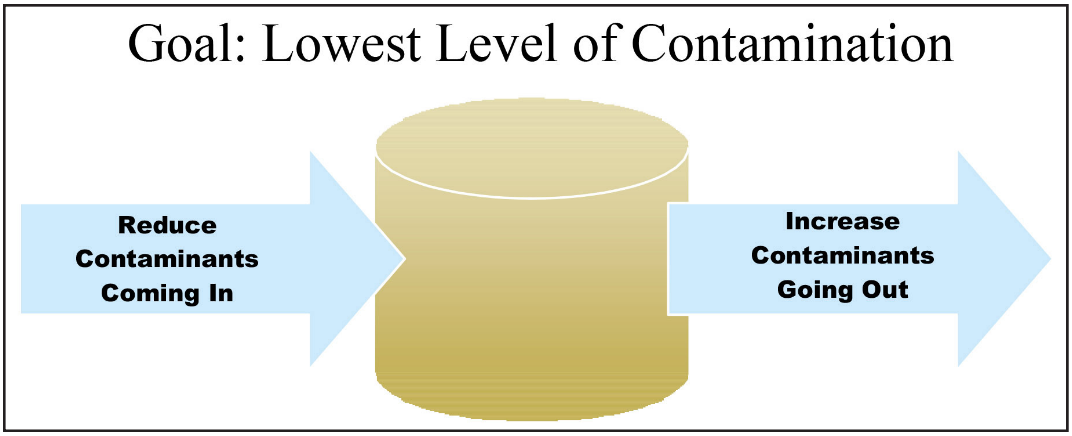


Figure 10 **The goal is the lowest possible evidence of contamination.**

various types of metals and alloys. The particle's composition indicates its source. The particle's shape reveals how it was generated. Abrasion, adhesion, fatigue, sliding and rolling contact wear modes each generate a characteristic particle type in terms of its shape and surface condition.

Solid contaminants can also be visually identified, provided they are of a commonly found origin. Sand and dirt, fibers, oxidation products, rust and metal oxides are examples of contamination debris that can be identified.

Taking Action with Oil Analysis

This article has covered the basics of common oil analysis tests and their significance. While the results of these tests are a powerful maintenance tool, they are useless if not monitored and acted upon.

Every particle, including soft ones, introduced to a rolling element bearing has the potential of damaging the bearing. The damage will appear when the roller passes the particle and it is indented in the metal. These debris dents cause a loss of the elastohydrodynamic (EHL) film thickness. The results are stress concentrations at the crater rim around dents. Cyclic contacts at these sites produce pressure a surge. Plastic deformation and tensile residual stresses can ultimately initiate micropits, which may grow into macropits.

Researchers from London's Imperial College, R.S. Sayles and P.B. Macpherson, showed that rolling element bearing life can be increased up to seven times by simply changing from a 40-mm filter to a 3-mm filter. Therefore, particle count information is the first line of defense. The rule of thumb that dirt generates dirt is a reality. Reliability is enhanced when particles are controlled. The goal should be to lower contamination to an acceptable level (Fig. 10).

The majority of particles in the oil are typically iron. Because iron acts as a catalyst, it will break down the oil and interfere with the elastohydrodynamic lubrication so critical in the gearbox. In short, it causes wear. Particles will wear down to the size of the lubrication film and even smaller. Microscopic images of these submicron particles in gear oil appear as round spheres. Like rocks on a beach, they have been worn round by countless passes through the gears. These particles appear black on a membrane. Theses membranes can be lifted by a magnet, because the small black particles are iron and they are magnetic.

Therefore, it is imperative that action be taken to control contamination. How can that be done? The goal for wind turbine owners and operators should not be the least expensive approach. Rather, the focus should be on three simple steps to enhance reliability. After all, we buy filters. But reliability is what we do. There are three steps to achieving this goal:

Step 1: ***set oil cleanliness targets.*** The proper cleanliness level is difficult to state in general. It is important to note that no gearbox has ever failed because the gear oil was too clean. Where availability and reliability are of great importance, the oil cleanliness target shall be higher. The American Wind Energy Association and the American Gear Manufacturers Association has released a technical standard that sets forth reasonable and attainable targets. Committee members took an engineering approach in setting lubricant cleanliness guidelines. The standard is entitled ANSI/AGMA/AWEA 6006-A01: Design and Specification of Gearboxes for Wind Turbines. The targets are found in Section 6 — Lubrication (Fig. 11).

Source of sample	ISO Code
Oil added to gearbox	16/14/11
Gearbox after factory test	17/15/12
Gearbox after 24 hour service	17/15/12
Gearbox in service	18/16/13

Figure 11 **The American Wind Energy Association and the American Gear Manufacturers Association have released a technical standard that addresses four contamination areas of particular importance.**

Water is a second key parameter to monitor and act upon. The AGMA/AWEA standard also includes guidelines for moisture contamination in Annex F. The caution level is 0.05% (500 ppm) and the critical level is 0.10% (1,000 ppm). So an effective contamination control program should aim for 0.05% or lower.

Step 2: ***take action to reach targets.*** Two specific actions are required. First, reduce contaminant ingression. In other words, keep particles from entering the gearbox. This requires good housekeeping procedures in the storage, handling, and dispensing of oil. Ensure the oil is kept clean and dry. Do not mix oils of an unknown origin. Avoid cross contamination by clearly labeling containers with the oil type.

New oil should always be introduced into the gearbox by means of a sufficiently fine filter (i.e., 3 microns). Studies show

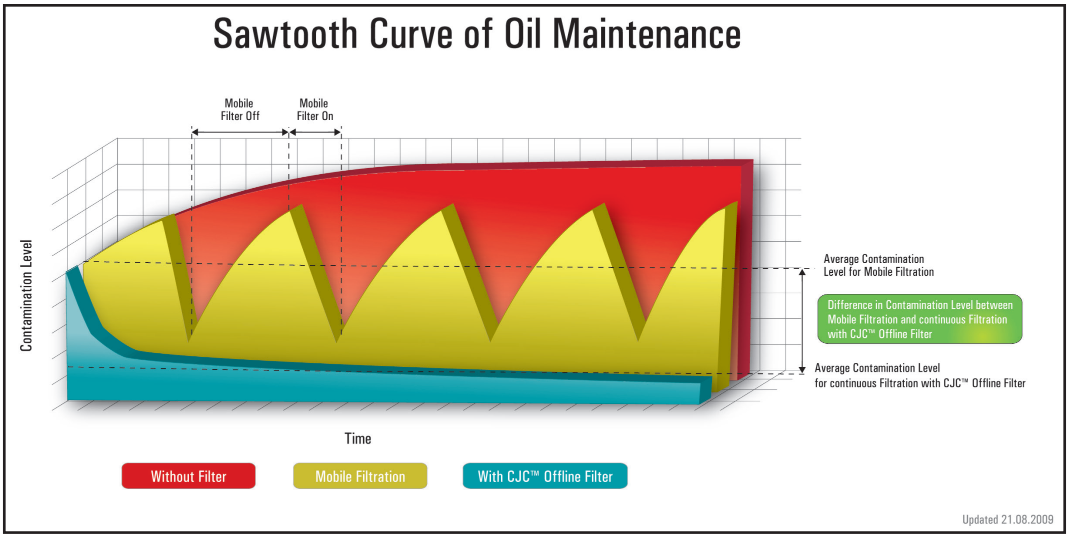


Figure 12 **While a filter cart will clean oil for a limited time, experience shows that when the filter cart is disconnected, the particle count quickly rises; i.e.—the "saw-tooth curve."**

that new oil is often highly contaminated. Therefore, use offline filters and filter carts to clean and dispense new oil from drums and totes. New oil should be considered contaminated until the opposite is proved. Portable containers can be directly filled from the cart. During maintenance events take great care to minimize the entry of contaminants. Add oil with the filter cart using quick disconnect fittings. Breathers should have a filter and desiccant to remove ambient dirt and moisture; use labyrinth seals and V-rings.

Next, improve filtration. Remove particles and water quickly. A well designed filtration system will effectively remove not only solid particles but also moisture.

Most large wind turbines have an inline filter located in the cooling system. However, these filters must out of necessity have a larger pore size than the oil film thickness, typically 10 micron or larger. Because the oil flow rates required by the cooler are high, a finer filter is not an option as this would make the inline filter too large for the nacelle. As a consequence these filters have a low dirt holding capacity and in some cases require frequent changes.

The solution is to supplement the inline filter with an offline filter. Offline filters are installed independent of the gearbox. Here a finer filter can be used, typically around three microns, because the oil flow requirements are less than 1 gallon per minute. Offline filters are depth type filters, meaning that they have a larger surface area than inline filters. Therefore they have a higher dirt holding capacity, providing a longer service life. Furthermore, the offline filter can run continuously, even during shutdown. Cellulose-based offline filters have the added capability of removing moisture via absorption.

Portable filters are not the ideal solution to maintain the oil cleanliness level. While a filter cart will clean the oil for a limited time, experience shows that when the filter cart is disconnected, the particle count quickly rises. This is known as the "saw-tooth curve," as Figure 12 illustrates.

A well designed contamination control system incorporating inline and offline filters will reach oil cleanliness targets and provide operational economy (Fig. 13). A common myth is that increased filtration costs outweigh the benefits of achieving cleaner oil. Savings usually outweigh costs by great margins because of longer filter service life, lower oil consumption, and extended gearbox and bearing lifetime.

In turbines where only an inline filter is installed, the replacement interval is six months or less. However, when an offline filter system is also installed, both filters only require replacement annually. The offline filter pump makes sure that all the

Figure 13 **Offline and inline filters are common in the wind industry and provide the optimum level of contamination control.**

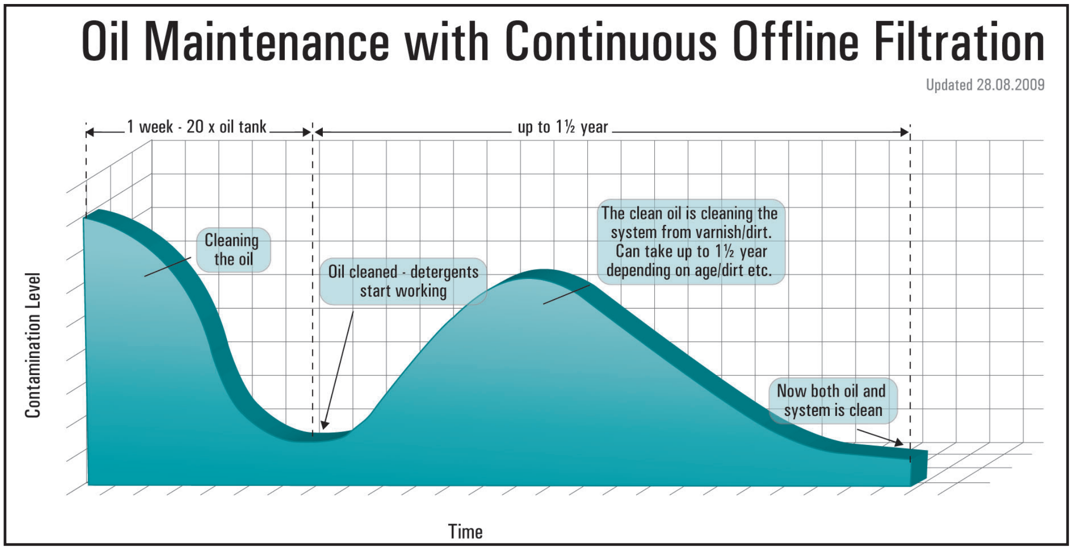


Figure 14 **Oil analysis is an essential component of improving wind turbine gearbox reliability; decisive action taken in response to the data collected will ensure a successful program.**

contaminated oil from the bottom of the gearbox is filtered and effectively used again.

Another improvement by installing the offline filter system is that it is able to filter gear oil even when the turbine is not connected to the grid. This is a major advantage during periods with low wind. In this condition the turbine may not be in constant operation. During this period the offline filter will continuously operate. In this way the gear oil will be clean when the turbine starts again.

The offline filter system is simple and easy to install; the benefits of the offline filter include:

- Improved lifetime of the gear oil
- Improved lifetime of gearbox bearings
- Reduced wear and tear on gearbox bearings
- Reduced the risk of bearing damage due to poor oil cleanliness
- Improved oil filtering

Offline and inline filters are common in the wind industry and provide the optimum level of contamination control.

Step 3: *monitor and maintain oil cleanliness.* Oil analysis will provide continual feedback on the condition of the gearbox and lubricant. It will also verify whether or not cleanliness goals are being met. If not, Step 2 — Take Action — can be applied.

Conclusion

Oil analysis is an essential component of improving wind turbine gearbox reliability. Decisive action taken in response to the data collected will ensure a successful program.

In summary, the three steps to improving reliability are:

1. Define targets for particle and water contamination.
2. Instigate remedial action as necessary to reach targets.
   a. Reduce ingression of contaminants.
   b. Improve removal of contaminants.
3. Monitor contamination levels against target levels and maintain safe levels.

Significant savings are achieved through longer oil and component lifetime. The relationship between lubrication quality and maintenance costs is inversely proportional. In other words, financial gains are made when the gear oil quality and cleanliness level are improved. It may take time to realize the benefits of this practice, but it is worth the effort. Figure 14 illustrates that time is required, but the results are indeed worthwhile. With this perspective in mind, oil analysis and upgraded filtration does not cost — it *pays* — to implement.

A successful oil analysis program will be one where the test data and analysis are coupled with the maintenance department's knowledge and expertise to provide the most effective maintenance practices.

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