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It is no surprise that gearbox failures have been linked to a lack of lubrication due to oil wear and contamination. Regular oil changes would seem to be the solution. However, changing oil in land-based wind turbines, or worse, swapping out their failed gearboxes, presents serious challenges due to the height of the turbines and their often remote locations. Offshore installations make for even greater hardship.

Oil changes at predetermined intervals are less than ideal because they are likely to result in the performance of expensive and time-consuming work more often than necessary and well before it is needed. Worse yet, they could result in oil changes occurring after damage to the gearbox has already begun.

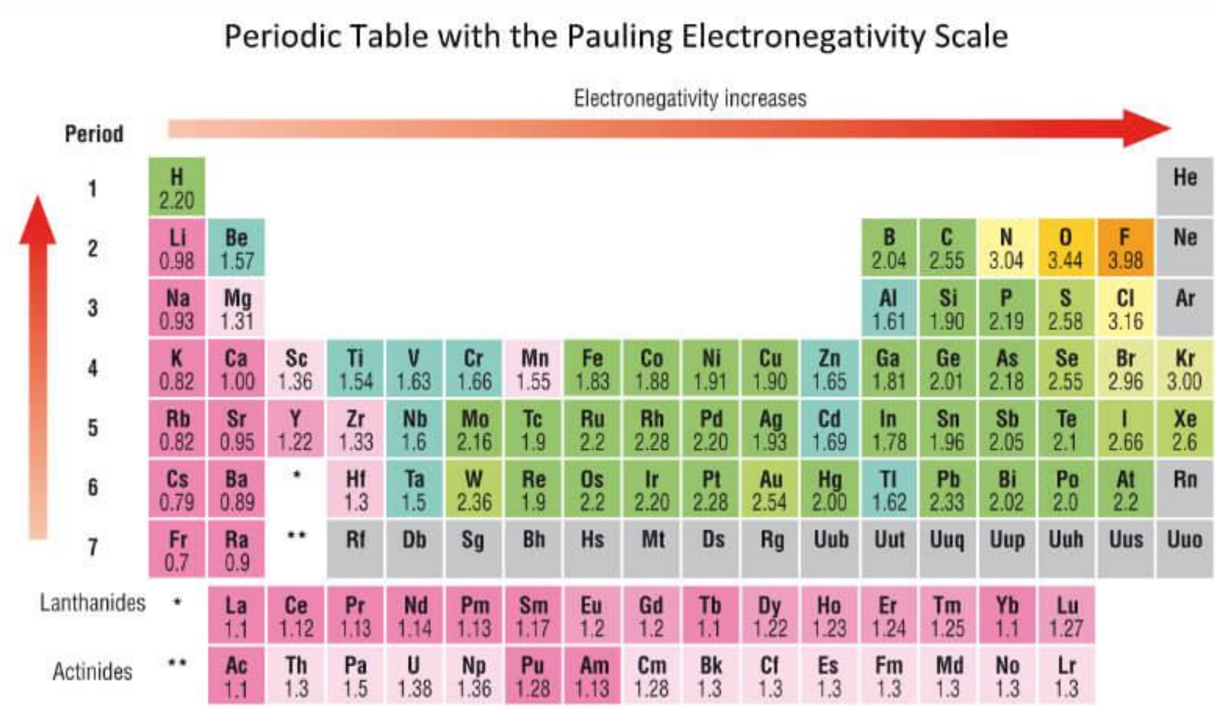
These shortcomings make monitoring gearbox oil for contamination and oil wear paramount for the longevity and cost-effective maintenance of wind turbines. Maintenance teams have responded to the need to monitor several ways. One calls for laboratory analysis while another proposes a continuous in-line solution:

- The laboratory solution of "sample and analyze" can provide useful information about the oil and the health of the gearbox. However, the technique is limited to discrete data points that correspond to each sample taken from the equipment. The problem is that oil does not always wear in a linear fashion, so events that cause damage to a gearbox can occur between sample points. Another disadvantage is the time and cost of pulling samples at remote locations, and from equipment as tall as 300 feet above the ground.
- Continuous real-time monitoring of the right set of parameters provides a trend of oil condition and supports a predictive approach to gearbox maintenance. Parameters of importance are acidity and oxidation, moisture contamination, and wear metal contamination.

An innovative monitoring method uses a sensor capable of measuring oil polarity and hence oil wear. Polarity is a reliable indicator of both the oxidation and acidity of the oil. The patented, proprietary sensor (developed by Voelker Sensors Inc. or VSI) also measures moisture content and the conductivity of the oil — which provides an indication of wear metal contamination.

Polarity, moisture, conductivity, and temperature. The essential oil factors − polarity, moisture, conductivity, and temperature − can tell a lot about a gearbox lubricant and better guide its maintenance.

The polarity of oil is a measure of the average difference in electronegativity of the atoms in the chemical bonds of the oil molecule. Each atom has an electronegativity number (shown in the Periodic Table below). When the difference between the electronegativity of two atoms in a chemical bond is greater than 0.7, that bond is considered polar.



Each element includes the Pauling Scale for electronegativity, a measure useful for monitoring oil wear.

Fresh gear oil is primarily comprised of carbon-carbon bonds. Because carbon atoms have the same electronegativity number, the electronegativity difference between the atoms in the bond is zero and the bond is considered non-polar.

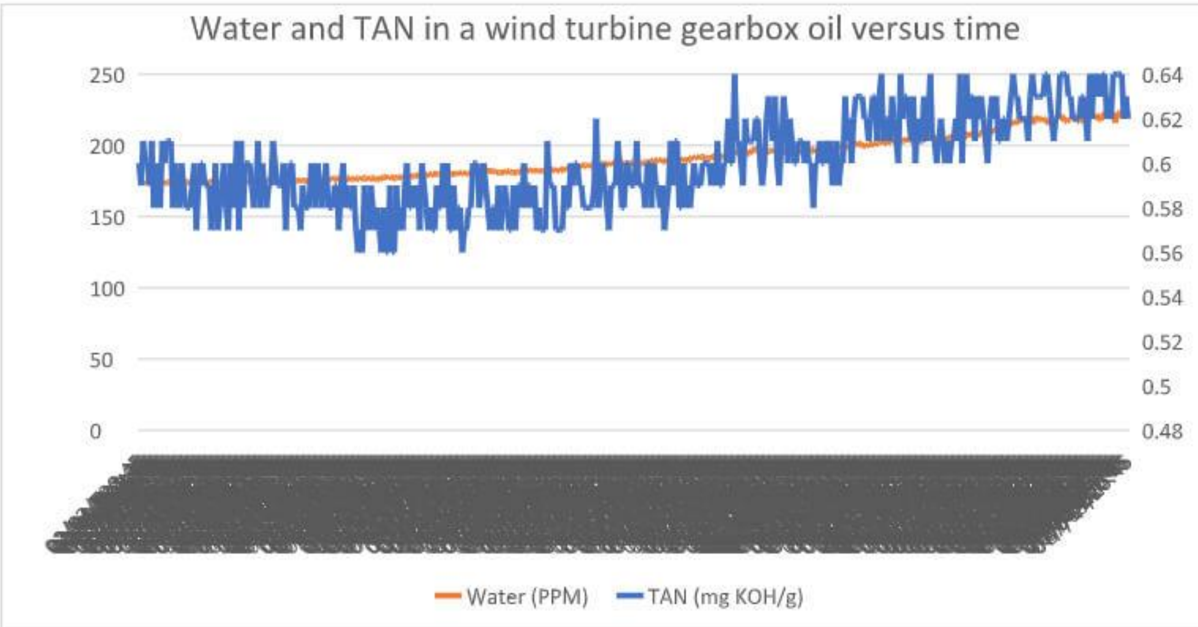
As oil wears, the carbon bonds of the base stock break, and oxygen frequently replaces the cast-off carbon. The electronegativity of carbon is 2.55, whereas for oxygen it is 3.44. The difference between them is 0.89, meaning that carbon-oxygen bonds are substantially more polar than the non-polar, carbon-carbon bonds they replace. As the oil stock breaks down, more of the carbon-carbon bonds are replaced by carbon-oxygen bonds, gradually increasing the oil's overall polarity.

The VSI sensor measures these small changes in polarity, providing a very sensitive oil wear detector.

Moisture in oil tends to equilibrate with the moisture in the air surrounding a gearbox. A higher moisture content can age oil, create oxidation on metal components in the equipment, and degrade the lubricating ability of the oil.

A conductivity increase indicates conductive contamination such as that from metals in the oil.

Temperature provides information about how hard the monitored equipment is working.



The orange line plots the water content in the oil of a wind-turbine gearbox from February to July, on the left scale in parts per million. The blue plot tracks the Total Acid Number (TAN) on the right scale.

An advanced sensor for continuous monitoring. The VSI sensor has been in use in wind turbines since 2013. The Water and TAN graph below are typical and are from an actual VSI installation. The data set covers a period of about five months. The moisture content of the oil shows an increase that is probably due to the relative humidity of the air changing from colder winter months to warmer summer months. The acidity of the oil is also seen increasing as the oil wears.

Imagine if the oil were only sampled on February 3 (TAN 0.60) and again three months later (TAN 0.59). One would reasonably conclude that the oil had not aged. However, if instead samples were taken on February 3 (TAN 0.60) and July 1 (TAN 0.65), a significant increase in acidity would be noted, but the perceived rate of aging (approximately 1.5% increase in TAN per month) would be significantly understated, leading to a dangerous overestimate of remaining useful life.

The VSI sensor installed in the oil stream on the exit side of a wind turbine's oil filter.

The plot of the continuously monitored oil shows that in fact, it failed to age appreciably for the first three months but then began to age rapidly (TAN increasing at a rate of about 5% per month). Because of the non-linear aging of the oil (which is typical), the oil in the later stages of this study was aging at greater than three times the rate that the sample and test approach would have suggested.

Final thoughts

Monitoring oil condition is essential to the maintenance of high-value and mission-critical equipment. The sample-and-analysis technique provides a wealth of information. However, the challenges of sampling and testing oil from remote, difficult to access equipment and the limited insight afforded into real-time oil condition point to the need for a better solution.

Continuous monitoring of wind-turbine gearbox oil has been shown to be an effective way to track and predict oil wear, and to prevent costly equipment failures.

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