AWEA AMERICAN WIND ENERGY ASSOCIATION

RP 108 Wear Debris Collection and Analysis for Wind Turbine Gearboxes

Operations and Maintenance Recommended Practices

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The following Recommended Practice (RP) is subject to the disclaimer at the front of this manual. it is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a working group of the AWEA Operations & Maintenance (O&M) Subcommittee. Principal Author(s):

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Purpose and Scope

The scope of "Wear Debris Collection and Analysis for Wind Turbine Gearboxes" addresses offline oil wear debris collection and analysis methods. Wear debris analysis (WDA) is an oil-lubricated equipment condition monitoring technique that has been used successfully in other industries. This guide provides recommended practices for offline oil wear debris collection and analysis methods that may be utilized to assess the health of a wind turbine gearbox by examining particles captured in the lubricant. It covers a niche between lubricant health monitoring and online wear debris monitoring, sharing some methodologies presented in recommended practices on those technologies. Please note that particle or particles mentioned in this RP are considered to include both wear debris and possible contaminations.

Introduction

The condition-based maintenance (CBM) goal is to move beyond an event-based maintenance strategy to avoid catastrophic failures. Online (real time) and offline (case by case) CBM strategies may be employed on wind turbines simultaneously. WDA, as it pertains to this RP, is an offline method.

When consistently collected and properly analyzed, gearbox wear debris reveals a wealth of component failure information, such as the failing component type, failure mechanism, and severity of wear. Armed with such information, the wind turbine operator can take appropriate maintenance actions that may mitigate or eliminate an unexpected failure.

WDA is a cost-effective bridge solution or supplement to fleetwide, online condition monitoring. A negative answer to any of the following questions will help determine whether WDA is an appropriate addition for a typical wind project:

- Is oil analysis providing preliminary failure warnings?
- Is filter clogging providing early-enough warnings?
- Is magnet (if equipped) picking up debris from applicable failures?
- Is particle tray (if equipped) data being consistently measured and recorded?
- Does the vibration system (if equipped) miss planetary stage failures?
- Does the real-time wear debris monitor (if equipped) provide the failing component type and failure mechanisms?

The most significant barrier to WDA in utility-scale wind turbines is handling and logistics of the large main gear oil filters. Once a sample can be consistently collected and efficiently delivered to a laboratory, existing analysis standards and procedures are readily available. Therefore, a successful gearbox CBM program will implement debris traps that are significantly smaller than the main gear oil filter. Further innovation may provide additional opportunities for automated debris collection and on-site analysis.

Methods of Wear Debris Collection

The discovery and analysis of wear debris is very subjective across the industry. The debris itself is rarely collected for analysis. Other industries have successfully extracted debris for laboratory analysis from small filters or employed purpose-built filters with removable test patches and used the data to enhance predictive maintenance. Several limited options may currently be available on wind turbines. However, purpose-built debris traps will provide a more consistent, cost-effective CBM solution.

Oil sample
The periodic oil sample is an unreliable source for collecting wear debris due to variation in settling time for large particles and the short duration of the sample collection.

Magnet sweep of filter housing or sump
Sweeping the sump with a magnet has long been used in the industry but is not a reliable collection method. It only collects ferrous debris and is inconsistent from one collection to the next. Nevertheless, the wear debris collected can be added to an oil sample bottle and sent to a laboratory.

Filter element
The main gear oil filter may be removed and sent to a laboratory, wherein a section of the filter is cut out and debris is removed for analysis. The logistics of shipping the filter and the difficulty of cutting a patch without introducing contamination into the wear debris, along with the cost of regularly sampling with such a method, is a low-value option. Very few laboratories are equipped to flush complete filters or cut sections from the filter.

Filter particle tray
Some main gear oil filters are equipped with a particle collection tray at the base of the filter. The tray has advantages over a sump sweep because it collects all ferrous and non-ferrous particles heavy enough to settle in the filter housing and may provide a more consistent collection volume during each collection period. Operators wishing to utilize the particle tray for consistent wear debris collection should develop a collection protocol during the filter change. The protocol may be as simple as taking care not to spill the debris from the particle tray during filter change and transferring as much debris as possible in a large oil sample bottle with the aid of a funnel. There is no known data available correlating the quality of particle tray debris to debris collected in the main gear oil filter.

Magnetic dipstick
Some gearboxes are equipped with magnetic dipsticks. The dipstick collects ferrous debris only. Removing debris from the magnet can be difficult. Other industries have installed removable sleeves on the magnets to aid in debris collection. Such a solution could be possible with wind turbine gearbox dipsticks.

Magnetic sleeve on main gear oil filter housing
Some main gear oil filter housings are equipped with magnetic sleeves to collect ferrous debris. As with magnetic dipsticks, the debris can be difficult to consistently collect. Nevertheless, the wear debris collected can be added to an oil sample bottle and sent to a lab.

Stalin—Moller filter patch
One operator has successfully added test patches to a commonly used offline filtration system filter. The patches collect a representative portion of the debris collected in the filter. They are easily removed and sent to a laboratory for analysis.

Sidestream trap from sample collection port
The National Renewable Energy Laboratory performed a series of tests utilizing a compact filter manufactured identically to the main gear oil filter. The compact filter collected debris from a sidestream taken from the oil sample collection fitting on the main gear oil filter upstream of the filter. The filters were sent to various laboratories employing differing methods of debris extraction, such as ultrasonic bathing or back flushing using economical equipment. A compact debris filter may provide the most consistent collection method for all types of debris. The filter may also provide consistent gravimetric data to trend debris generation from one sample to the next, especially if normalized for production during each interval.

Laboratory Analysis

The analysis laboratory has an impressive array of test methods at their disposal. In evaluating appropriate test methods, it is important to understand the cost and expected resolution of the data. A recommended approach is to run an abbreviated test panel that may trigger additional testing. For example, a healthy gearbox WDA analysis may consist of a backflush of the filter element, or dilution of debris-laden lubricant in a sample bottle, followed by an automated particle count. At some predetermined quantity and size threshold, particle characterization is triggered. If fatigue or wear is indicated, elemental analysis and alloy composition may be triggered. Prior experience with particular make and model failure modes will help establish alarm levels. Each analysis trigger acts as an alarm that may result in additional maintenance activity.

ASTM D7919 − 14 (2017), Section 7.5 provides a detailed description of available debris analysis techniques. It references at least eight ASTM standards applicable to WDA.

Level 1 data: Weight, count, size
- Visual
- Gravimetric
- Automated counting (ASTM D7685)

Level 2 data: Wear debris characterization
- Run-in or failure, rubbing, surface fatigue, corrosion, sliding, or cutting
- Microscopic evaluation for morphology (D7684)
- Analytical ferrography (D7690)

Level 3 data: Elemental analysis and alloy composition
- Identify component by alloy, such as bearing, gear, cage, or housing
- Iron (Fe), chromium, copper, nickel, and other alloys
- Atomic emission (ICP-AES), (D5185), with acid digestion of large particles
- Rotating disc electrode atomic emission spectrometry (RDE-AES), (D6595)
- X-ray fluorescence spectroscopy
- Scanning electron microscopy energy dispersive X-ray

WDA Implementation for Gearbox CBM

A general guideline for implementing WDA by wind project owner and operators is provided in this section. Items listed under most of these steps are following a logical sequence for users of this RP to evaluate. Given the diverse nature of wind projects, it is not uncommon for WDA implementation to vary from one project to another.

Step 1: Gather information

- Identify and evaluate effectiveness of existing condition monitoring
    - o Supervisory control and data acquisition (e.g., chip detectors, filter bypass, and differential pressure)
    - o Filters (main or sidestream) and magnets
    - o Online wear debris monitoring
- Gearbox history by make and model
    - o Failure modes, age, wind regime, oil condition history (e.g., International Organization for Standardization particle count cleanliness, water, and metals)
- CBM budget

Step 2: Scope WDA program within budget, need, and entire oil condition monitoring program

Option 1 Additional analysis of debris suspended in periodic oil sample ($50-$150 semiannual analysis)

- o Ferrography, wear debris count, chemical elemental
- o Understand limits, especially eight micron particle size limit for chemical elemental analysis

Option 2 WDA, offline ($0-$250 hardware, $75-$500 semiannual samples)

- o Review hardware options to trap particles over a periodic operating interval (e.g., 6 months)
- o Select laboratory, identify analysis methods, determine costs

Option 3 Online wear debris monitor ($3,000-$10,000 hardware plus monitoring costs)

- o Consider installing online wear debris monitor hardware on turbines that have been selected based on WDA warnings, versus installing on all turbines, which may reduce large capital expenditures
- o Support online data with hard evidence from more sophisticated WDA analysis

Step 3: Determine particle collection method

- Eliminate inconsistent methods, such as oil sampling, sump sweeps, or wiping magnets with a rag
- Select system based on existing hardware, logistics, and analysis costs
    - o Particle tray (consistent samples?)
    - o Magnet (ferrous limitation?)
    - o WDA large filter element (low up-front cost for occasional samples, but high long-term logistics and evaluation costs for periodic trending)
    - o Dedicated particle trap (i.e., sidestream filter, filter patch)

Step 4: Specify analysis protocol

- Confirm laboratory can process site debris collection format
    - o Large filter
    - o Compact filter
    - o Field-prepared patch

- Confirm laboratory sample preparation provides consistent results
    - o All collected debris needs to be counted
    - o If back flushing, be aware of filter size limitations
    - o If ultrasonic bath, make sure to use entire or partial filter with consistent fluid bath depth
- Normalize particle count data with reference to production or operating hours

Step 5: Establish baseline debris profile

- Write collection protocol
    - o Consistent periodic samples
    - o Sample interval (6 months)
- Select proxy machines
    - o Highest production, several of each make/model gearbox
- Collect supporting data
    - o Production, oil change, filter change, repair, extraordinary loading events
- Compare and validate oil sample analysis with WDA

Step 6: Monitor basic data, identify outliers, and escalate analysis

- Level 1 data: visual and automated counting
- Level 2 data: microscopic wear debris characterization
    - o Run-in or failure?
    - o Rubbing, surface fatigue, corrosion, sliding, cutting
    - o Use to inform visual inspection
- Level 3 data: elemental and alloy composition
    - o Identify component type, such as bearing, gear, cage, and housing

Step 7: Act on alarms

- Escalate analysis (level 1 to 2, 2 to 3)
- Visual or borescope inspection of equipment (use WDA to inform)
- Additional CBM equipment (wear debris, vibration)
    - o Online or portable?
- Reduced power output, turbine control parameter changes
- Repair

Step 8: Close gaps

- Review collection, analysis, alarms, and action steps
- Evaluate cost-effectiveness and potential savings from the WDA program for management

Summary

Wear debris holds a wealth of diagnostic data for gearbox health monitoring. It is often discarded or neglected during periodic oil sampling. Economical and consistent debris collection is the key to a successful WDA program. WDA will improve fault detection over traditional oil analysis and will bridge the CBM gap between oil analysis and online CBM systems. Its advantages are simple implementation and low labor impact if an appropriate debris collection method, such as compact filters, is adopted. Analysis laboratories are equipped with a broad spectrum of wear debris analysis methods that can be tailored to the needs and budget of any wind farm.

References

1. A. Becker and P. Stanhope; "Improvements to Filter Debris Analysis in Aviation Propulsion Systems"; Air Vehicles Division Defence Science and Technology Organisation; DSTO-TR-2773; December 2012 (Unclassified).

2. J. Schindler, M. Steves and G. Rosenberg; "Lubricant Condition Monitoring Using Filter Debris Analysis"; www. machinerylubrication.comLubr/Read/630/filter-debris-analysis; (article was reprinted with permission from the Joint Oil Analysis Program. It was presented at the International Condition Monitoring Conference held in Pensacola, FL., on April 18-22, 2004. The article is a condensed version of the original paper.)

3. D.A. Roberts and S. Sheng; "Compact Filter Debris Analysis for Wind Turbines"; Drivetrain Reliability Collaborative Meeting, February 21–22, 2017.

4. S. Sheng and D.A. Roberts; "Improving the Analysis of Gear Oil Debris with a Compact Filter"; Windpower Engineering and Development, April 27, 2017.

5. S. Sheng; "Monitoring of Wind Turbine Gearbox Condition through Oil and Wear Debris Analysis: A Full-Scale Testing Perspective"; Tribology Transactions, Volume 59, Issue 1, Published online: 22 Feb 2016.

6. S. Ebersbach, Z. Peng, and N.J. Kessissoglou; "The Investigation of the Condition and Faults of a Spur Gearbox using Vibration and Wear Debris Analysis Techniques." Wear, Volume 260, Issues 1-2, (2006): 16-24.

7. T. Robert Shives (Ed.); "Advanced Technologies in Failure Prevention"; Proceedings of the 43rd Meeting of the Mechanical Failures Prevention Group, Mechanical Failures Prevention Group. Meeting, Cambridge University Press, Jun 28, 1991.

8. A. M. Toms and M. P. Barrett; "Using Filter Debris Analysis to Identify Component Wear in Industrial Applications"; Insight Services white paper.

9. Z. Peng, Z. and T.B. Kirk; "Computer image analysis of wear particles in three-dimensions for machine condition monitoring." Wear, Volume 223, Issue 1, (1998): 157-166.