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AWEA Operation and Maintenance Recommended Practices

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WIND TURBINE GEARBOX OIL SAMPLING PROCEDURES

PREFACE

The following Recommended Practice is subject to the Safety Disclaimer and usage restrictions set forth at the front of AWEA's Recommended Practices Manual. It is important that users read the Safety Disclaimer and usage restrictions before considering adoption of any portion of this Recommended Practice. At any time if in doubt consult your OEM representative for additional details.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance Working Group. As well as Technical and Commercial information made public industry wide. I have added specifics based on my individual career experience as well.

PURPOSE AND SCOPE

This Recommended Practice discusses the methods for taking clean and respective wind turbine gearbox oil samples. Samples that are taken properly will provide the user with accurate data. In general, we want oil samples to effectively represent the body of oil about which we desire information to increase the effectiveness of lubrication and machine decisions. Maximizing data density, minimizing data disturbances, and selecting of goal-driven sampling frequencies make up the components of any sampling objectives.

The general procedure applies to wind turbine lubrication systems. There are several different wind turbine gearboxes and lubrication systems. This paper will focus on two commonly used systems. These recommendations will give proper procedure for the handling of containers and oil before and after samples have been taken to ensure that data obtained from oil analysis is accurate. **Fluid Life NOTE**: it is important to collect the samples and get them to your ***Fluid Life Testing facility*** as soon as possible, as this information is time sensitive and serves as mission critical early warning to your high dollar assets.

INTRODUCTION

Standardizing oil analysis from a specific sampling port is important. Taking samples from different ports may result in providing skewed samples to the laboratory for analysis.

Taking respective oil analysis samples from the same port on each turbine can provide data to wind turbine personnel that will allow accurate comparisons between turbines. Establishing which turbines should be scheduled for maintenance can then be easily assessed.

GEARBOX OIL SAMPLING PROCEDURES

1. PREPARING FOR OIL SAMPLING

1.1. Normal samples are typically taken in 3.5oz bottles. If extra laboratory tests are required taking a larger volume sample may be required. ***Working with your Fluid Life Lab you can speak with your assigned (Account Manager) for any assistance and guidance as require.***

1.2. Oil samples should be placed in a clean unbreakable container. Oil manufacturers and analysis laboratories carry special bottles available upon request and typically purchased with your testing program.

1.3. Before sampling, bottles must be clearly marked by labeling with the following information:

1. Company/Site Name
2. Turbine Number
3. Gearbox Model/Type
4. Oil Manufacturers
5. Oil Name
6. Date Sampled
7. Time Sampled

Labeling ensures oil analysis is associated with the correct oil sample for data tracking purposes.

Fluid Life NOTE: Fluid Life also has developed digital tools, bar codes and mobile apps to increase speed and efficiency.

2. PRIOR TO TAKING THE GEARBOX OIL SAMPLE

2.1. If the turbine has been running, turn the oil pump on for 1-minute before taking an oil sample. If the turbine has not been running, make sure to activate the oil pump for a minimum of 5 minutes before taking sample.

2.2. Make sure tubes, bottles, sample ports, and hoses are free of debris before taking the sample. This ensures no residual contaminants enter your sample, Fluid Life can provide these for your use.

2.3. Oil samples must be taken from a port before the oil filter. Samples must be taken from the same location each time to create a solid comparison. On all systems, only take samples from the recommended locations. (See Figures A & B)

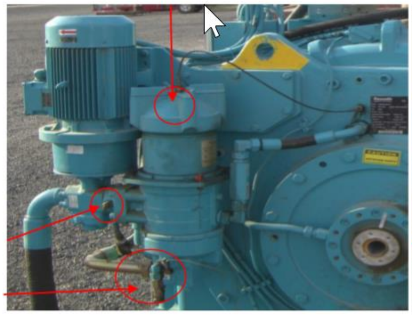
Figure A. System 1.

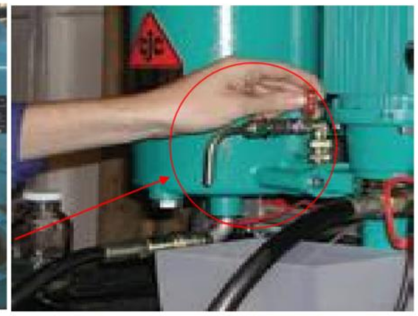
Figure B. System 2.

3. TAKING THE OIL SAMPLE (SYSTEM 1)

3.1. Purge with approximately the same amount of oil as the sample bottle size from a recommended sampling port. (See Figure A.)

3.2. After purge sample is drawn seal the bottle immediately.

3.3. Open the clean sample bottle when ready to take the sample.

3.4. Open clean bottle and place under sample port. Make sure bottle is not touching the sample port.

3.5. Fill the 3.5oz clean bottle 80-90% full and place the cap on immediately.

3.6. Replace any hoses or caps on oiling system to ensure no leakage before exiting.

4. TAKING THE OIL SAMPLE (SYSTEM 2)

4.1. Open and close the recommended sampling port valve several times to purge the system, draining the purge oil into a container. Purge with approximately the same amount of oil as the sample bottle size.

4.2. After purge sample is drawn seal the bottle immediately

4.3. Open the clean sample bottle when ready to take the sample.

4.4. Open clean sample bottle and place under the sample port. Make sure bottle is not touching the sample port.

4.5. Fill the 3.5oz clean bottle 80-90% full and place the cap on immediately.

4.6. Shut off valve and ensure there are no leaks before exiting.

<u>SUMMARY</u>

Proper gearbox oil sampling methods are crucial for comparing samples from one turbine to another or from sample to sample in the same turbine. This will assist in properly scheduling maintenance, as a good track record will be established. Many gearboxes have different filtration systems and sampling methods, however taking a clean sample from the same port will provide a good respective sample on a consistent basis. Even though a typical wind farm operator will do maintenance twice a year or during low wind season it is imperative that samples are collected and sent to the testing lab in a timely manner for multiple and varied reasons.

WIND TURBINE GEAR LUBRICANT FLUSHING PROCEDURES

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PURPOSE AND SCOPE

This Recommended Practice discusses the proper methods of wind turbine gearbox flushing and oil conversion procedures to optimize oil change quality and prevent carryover of additives sludge and debris from used oil to new oil.

There are numerous wind turbine gear lubricant oil system types; however, this paper will focus on a commonly used lubrication system. The general procedures can easily be adapted to other lubrication systems with similar results.

Base oil types associated with this Recommended Practice are Polyalphaolefin (PAO) and Petroleum oil (mineral oil). Other base oil types are not associated with this paper.

INTRODUCTION

Sludging on internal wind turbine gearbox components is common. If these components are not cleaned or flushed properly during an oil change, the quality of the new gear lubricant is compromised causing poor future performance.

Simply draining and filling a wind turbine gearbox may not be adequate. Doing so might leave deposits which could cause new oil foaming, increased wear such as micro pitting, shortened oil life and making oil analysis difficult to interpret due to used gear lubricant additive carryover into the fresh gear lubricant. Specific flushing procedures are required to optimize oil change gear lubricant quality.

FLUSHING PROCEDURES

1. PREPARING THE GEARBOX FOR THE OIL CHANGE.

1.1. Take an oil sample of the current used gear lubricant from the gearbox at the recommended location, following established sampling procedures. All samples should be taken from the same location consistently. Purge the oil sample port to ensure respective sample is taken.

1.2. A cleaner may be added to loosen up dirty or sludgy gearbox deposits and assist in the flushing process. Consult with the oil supplier for direction as to the specific type and proper usage of cleaner.

2. DRAINING THE USED GEAR LUBRICANT FROM THE GEARBOX.

2.1. Take an oil sample.

2.2. Fabricate a drain plug with the correct fitting to adapt to a drain hose. (See Figure A.)

Figure A.

2.3. Connect the used oil hose to the reservoir drain valve.

2.4. Connect this hose to the waste oil tank at the lube truck.

2.5. Start draining the gearbox oil by opening the valve. Draining of used oil is aided by using a pump, vacuum, or both.

2.6. Open the oil filter housing, discard the used oil filter, and thoroughly drain the filter housing.

2.7. Clean the inside of the filter housing by hand. (See Figure B.)

Figure B.

2.8. Remove the by-pass pressure release valve and hose next to the gearbox heat exchanger/cooler and drain any oil in the hose. (See Figure C.)

Figure C.

2.9. Clean the by-pass pressure release valve by hand with spray cleaner (i.e., Brake Clean).

2.10. Re-install the by-pass pressure release valve and hose next to the gearbox heat exchanger.

2.11. Remove the thermostatic by-pass valve block which is found on the bottom of the filter housing and clean by hand. (See Figure D.) Then remove the thermostat assembly from the thermostat block and clean. (See Figure E.)

CAUTION: Do not remove the brass pin from the thermostat barrel.

Figure D.

Figure E.

2.12. Re-install the thermostatic by-pass valve assembly and block.

2.13. Remove the hose from the system relief valve located between the filter housing and oil pump and drain any oil from the hose. (See Figure F.)

Figure F.

2.14. Remove the system relief valve and clean if needed.

2.15. Re-install the relief valve.

2.16. Remove the 2-inch plug at the top of the gearbox planetary (See Figure G.) Purge/spray the gearbox planetary with approximately 5 gallons of new gear lube.

Figure G.

2.17. Re-install the 2-inch plug at the top of the gearbox planetary.

2.18. Continue to drain the oil from the gearbox.

2.19. Through the gearbox inspection cover (See Figure H), purge/spray the interior gearbox housing, gears, bearings and shafts using 5-gallons of new gear lubricant.

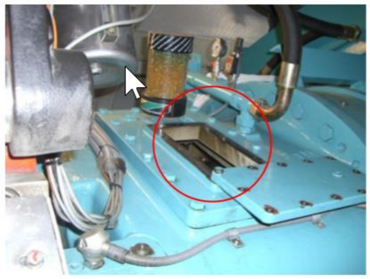

Figure H.

2.20. Continue to drain the oil from the gearbox.

2.21. Close the gearbox drain valve.

2.22. Place a drain pan under the gearbox drain valve and open the valve.

2.23. Use a magnet to swab into the gearbox through the drain port for any metallic wear debris.

2.24. Reconnect the hose to the drain port and open the drain valve.

2.25. Drain the external heater, if so equipped. (See Figure I.)

Figure I.

2.26. Disconnect the oil level sensor and clean.

2.27. Take the top of the oil float level housing off and clean out the sensor housing and oil float indicator by hand. (See Figures J and K.)

Figure J.

Figure K.

2.28. Install a new gasket for the oil sensor container.

2.29. Re-install the oil level sensor.

2.30. Install a dedicated flush filter. This flush filter can be reused for up to 5 turbine oil changes during the flush and rinse phases only.

2.31. Re-install the gearbox inspection cover.

3. FLUSHING PHASE

3.1. Prior to flushing the gearbox, all oils located on the oil change truck/trailer need to be filtered with a 5-micron filter to keep any possible debris from the lube truck tanks or oil transfer from entering the gearbox.

3.2. Close the gearbox drain valve.

3.3. Fill the gearbox to the recommended oil level with gear lubricant.

3.4. Turn on the heater pump to circulate the oil in the heater sump, if so equipped.

3.5. Turn on the gearbox lubrication pump and let the turbine pinwheel for up to 60 minutes at low speed. This is to be done with NO Load.

3.6. Take a one-quart sample of gear lubricant from the gearbox and label Flush Sample and include turbine number and date on the bottle.

3.7. Repeat Steps 2.5 through 2.31 from “Draining the Used Gear Lubricant in the Gearbox” section of this document. Re-clean the bypass pressure release valve, the thermostatic bypass valve block, the system relief valve, and the oil level sensor only as required.

4. RINSING PHASE

4.1. Prior to rinsing the gearbox, all oils located on the oil change truck/trailer need to be filtered with a 5-micron filter to keep any possible debris from the lube truck tanks or oil transfer from entering the gearbox.

4.2. Close the gearbox drain valve.

4.3. Fill the gearbox to the recommended oil level with gear lubricant.

4.4. Turn on the heater pump to circulate the oil in the heater sump, if so equipped.

4.5. Turn on the gearbox lubrication pump and let the turbine pinwheel for up to 30 minutes at low speed. This is to be done with NO Load

4.6. Take a one-quart sample of gear lubricant from the gearbox and label Rinse Sample and include turbine number and date on the bottle.

4.6.1. Repeat Step 3.7. Close the gearbox drain valve.

4.6.2. EXCEPTION FROM Step 2.29: Install new gear lubricant filter for final fill phase. Retain flush filter for re-use up to 5 times.

5. FINAL FILL PHASE

5.1. Close the gearbox drain valve.

5.2. Pump up new, filtered gear lubricant until the gearbox sump reservoir is full as indicated by the gearbox sight glass.

5.3. Install a new desiccant filter/breather.

5.4. Inspect the gearbox inspection cover gasket and replace if necessary.

5.5. Turn heater pump and lube oil pump on to circulate gear lubricant throughout the system. Turn off pumps and recheck the oil level to ensure oil level is between the low and high –level indicators. Top up as needed.

5.6. Turn on the gearbox lubrication pump and let the turbine pinwheel for 15 minutes at low speed, and with NO Load.

5.7. Take a one-quart oil sample and label Final Fill and include turbine number and date on the bottle. Check for oil leaks at all fittings & connections.

5.8. Check the oil level 30 minutes after shutting the turbine down to ensure the gearbox oil is at full indicator.

5.9. Clean up and affix new oil label on the gearbox.

SUMMARY

Some wind turbine gearboxes are particularly dirty from deposits left by specific gear lubricant breakdown and/or outside contaminants. It is important to understand that a good flushing process includes draining the gearbox and all associated areas. These areas include hoses, thermostat, oil float indicator, check valves, heater, and cooler. Neglecting to address all of these areas that are known to hold old, contaminated gear lubricant will result in diminished new oil quality. It is also very important to manually clean all sludge surfaces such as: filter housing, check valves, oil float indicator and thermostat. This is to assure contaminants are not carried over to the new gear lubricant. By evaluating oil analysis comparisons between the used gear lubricants, flush, rinse and final fill gear lubricant samples, it is possible to determine final fill gear lubricant quality. The oil analysis used to properly evaluate the gear lubricant samples should include:

1. Viscosity
2. List of items
3. ICP Analysis
4. Water PPM
5. Particle Counting
6. Foam testing

Foaming is not normally tracked during regular oil analysis, however during the flushing procedures it is important to understand that residual components left from the used oil can cause foaming in the new gear lubricant. Although additive concentrations in the used gear lubricant are normally flushed adequately by the end of the Flush Phase, foam values may still remain and show up in oil analysis until after the Rinse Phase. This indicates that the Rinse Phase is necessary and provides a better final fill gear lubricant quality. **Fluid Life** once again can assist and educate you as to this anomaly and any additional information as required.

FACTORS INDICATING GEAR LUBE OIL CHANGE

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PURPOSE AND SCOPE

This Recommended Practice discusses the determining factors that could indicate a gear lube oil change.

INTRODUCTION

There are many factors that could cause an oil change in a wind turbine gearbox. This paper will provide factors to consider that contribute to a condition-based gear oil change. The decision to perform a condition-based oil change is founded on the overall condition of the oil which is evaluated using turbine and gearbox manufacturer condemning limits and industry standards. In some cases, filtration or dehydration corrective actions may be employed to extend the service life of the oil. **Fluid Life** can assist and educate you on these actions and in many cases additional testing procedures can be used to confirm actions as well.

FACTORS INDICATING GEAR LUBE OIL CHANGE

1. CONTAMINATION

1.1. Externally Generated Contamination

External contamination particles can be derived from the environment or incompatible substances added to the oil. These include ingress of water due to weather conditions and natural aspiration through a breather, or salt spray, sand, dirt, dust, clay, silicates, and incompatible lubricants. Some contaminants may react adversely with oil additive packages in the lubricant, thus, damaging lubricant quality and may not be able to be remedied by filtration and may even require a system flush.

1.2. Internally Generated Contamination

In some cases, internally generated contaminants have the same characteristics as the external type. Internally generated contamination consists of wear debris particles, decomposition sludge and oxidation by-products.

2. LUBRICANT DEGRADATION

Additive degradation, in some cases is known as additive depletion. Some lubricant types may have slightly reduced additives while staying within acceptable limits and are still serviceable. Some other lubricant types may be characterized by the reduced ability of the oil’s additive system to perform its intended function. Once depleted, organic acids may form, creating sediment, sludge or varnish particles that can cause deposits and increase the viscosity of the oil, makeup oil or even after an oil change if not flushed properly.

3. GENERAL GUIDELINES FOR LUBE OIL CHANGES

By necessity these guidelines are general in nature. These limits and/or rules cannot cover every conceivable situation but are meant to be a guide for you to make cost effective and reasonable corrective actions. These guidelines are consistent with ANSI/AGMA/AWEA 6006-A03, Standard for Design and Specification of Gearboxes for Wind Turbines or IEC ISO 61400-4-2012.

3.1. WATER CONTAMINATION

Water is always present in some minute amount. There are different phases for water in oil:

1. In solution (not visible to the unaided eye).
2. Emulsified (causing the oil to appear hazy or milky).
3. Free (settling on the bottom of the gear case or sample bottle).

Different phases are dependent on several factors such as oil and additive types, amount of water present, and the temperature of the oil when it is observed.

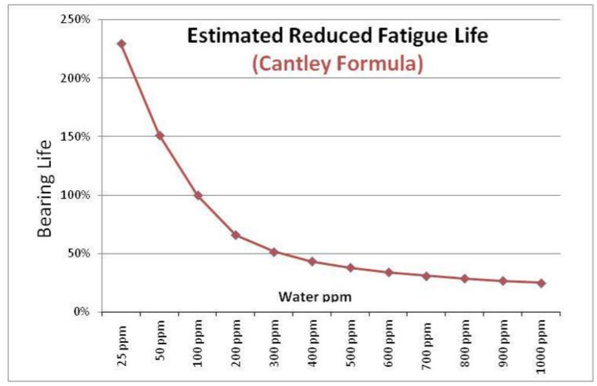
AWEA 6006-A03 outlines water levels at 500 ppm (0.05%) as borderline and 1000 ppm (0.10%) as unsatisfactory [1], however water saturation levels change with temperature fluctuations i.e., warm oil holds more water than cold oil. This means that water in solution at hot temperature could cause some water to become free water when the oil cools from turbine down time. Water levels change with season and climate making it important to use the AWEA recommended ASTM test method, D6304-C outlined in the AWEA Recommended Practice “Wind Turbine Gear Oil Analysis Test Methods”.

Water at elevated parts per million may contribute to [1]

1. Accelerated additive depletion.
2. Accelerated oxidation.
3. Interfere with an active lubricant film formation.
4. May react with additives to form residue on critical surfaces and plug filters or clog spray nozzles.
5. May react with the base fluid or additives to promote the hardening of elastomers or premature failure of internal coatings such as paints.
6. May react with base fluid where additives can increase acidity.
7. Direct contact with metal surfaces can produce rust particles that contribute to abrasive wear and act as an oxidation catalyst.
8. Corrosion etch pits may initiate fatigue cracks.
9. Under specific conditions, may lead to hydrogen embrittlement that promotes propagation of fatigue cracks.

Bearing manufacturers and engineers have studied the effects of water in oil has on bearing fatigue and gear life and determined that increased water levels in wind turbine gear oil is related to increased gear wear and bearing fatigue life. A bearing manufacturer's research test provides data indicating water greater than 100 ppm (0.01%) will reduce bearing life significantly.[2] Another example of water in oil research is referred to as the Cantley Formula. [2, 3] (See Chart A.)

Chart A



Cantley Formula
L = (100/X)^0.6.
X = PPM Water
L = % of Rated Bearing Life

The Cantley Formula water chart indicates that 100 ppm water in gear oil will result in 100% bearing life. It is important to keep water levels down as low as possible to optimize bearing life.

Excessive water in wind turbine gear oil has been associated with gearbox problems such as sludging, micro pitting, filter plugging and short oil and gearbox life [5]. The IEC/ISO committee in late 2012 published the newest wind turbine standards document IEC 61400-4-2012 which indicates lower water limit guidelines, <300 acceptable, 300 to 600 caution level and >600 Alarm level [6] which are lower than AWEA 6006-A03 water limits.

3.2. Particulate Levels

Particle counting for gear oil in wind turbines gearboxes is performed at laboratories by Solid Contamination Code, ISO 4406-1999. Particles are counted in three ranges, >4, >6 and >14-micron particle sizes and the results are reported as x/x/x cleanliness code. Most turbine manufacturers consider that normal or the target cleanliness code is -/16/13 and borderline levels are -/17/14, while levels of -/18/15 or greater are considered unsatisfactory.

Filtration has much to do with particle count. The >4-micron particle count will be reduced if the filtration is switched from the standard 10-micron filter to a 5-micron filter.

If improved filtration or installation of a new filter does not control particle contamination to the target level, this would be a condemning limit for the gear oil.

3.3. Sediment, Sludge and Varnish Levels

Any visible sediment or discoloration is cause for unsatisfactory oil condition [1]. Verify that a clean sample is taken, and visible sediment is not from the sampling process. If it is confirmed that the sample was taken without debris contamination, then the source of the sediment could be from the gear oil. The source and type of contamination will determine what reasonable corrective action should take place.

3.4. Total Acid Number Values (TAN)

Although general limits for TAN level increase above new gear oil values vary by product chemistry type, lubricant suppliers should be able to give guidance regarding the level of TAN increase specific to their individual gear oil and at what point they consider recommending corrective action which could include changing the oil. General industry condemning limits are 2.0 over new oil value.

3.5. Viscosity Levels

The viscosity of the oil can change either up or down. The viscosity of wind turbine gear oil is normally 320 mm2/sec, formerly centistokes (cSt) which is referred to as ISO VG 320. Per the standard, each viscosity grade ranges + or – 10%. Thus, for an ISO 320 fluid, the range would be 288 to 352 cSt. Results that fall outside of this range either high or low would not meet turbine or gearbox manufacturer's viscosity requirements and could result in a recommendation for corrective actions or oil change.

3.6. Foam Tendency

One laboratory test not normally done on wind turbine gear oils during the regular 6-month oil sampling period is the ASTM D892 foam test. Foaming can cause many issues from filter plugging to reduced oil film thickness. In this test [3] air is blown into the test gear oil to create foam which builds up on top of the oil. It is measured at the end of the test and after a 10-minute settle time. If the foam bubbles break within the 10-minute settle time the fluid is considered to have good foaming resistance, however if there is any foam after the 10-minute settle time then the fluid may not be performing as designed and the oil may need to be targeted for an oil change.

4. OIL CHANGE CONDEMNING LIMITS

The factors indicating a gear oil change in Chart B are general and not necessarily specific to any one gear oil. (See Chart B.) It is important to contact the oil manufacturer and ask for their specific condemning limits. These condemning limits can be used as a guide in determining when an oil change is needed. Fluid Life as your testing partner can gladly apply these as well as working with you at your discretion to tailor these as specific as possible in your program.

Chart B

Factors Indicating Gear Lube Oil Change				
	Method	**Measure**	**Monitor**	**Change or Reconditioning**
Water	ASTM D6304-C	ppm	300 to 600	600
Foam (@10 min settle)	ASTM D892	ml	<10	>10
Particulate Levels	Cleanliness Code	>4/>6/>14	-/17/14	-18/15
Total Acid Number	ASTM D664	mg/g KOH	1.5 over new	2.0 over new
Viscosity	ASTM D445	mm^2/sec (cSt)	<304 or >336	<288 or >352
Sediment	Visual in oil sample			Any
Sludge or Varnish	Visual	N/A	N/A	Early filter replacements
Additive	ICP or AES oil analysis ASTM		Subject to Oil Mfg	Subject to Oil Mfg

Factors Indicating Gear Lube Oil Change				
	Method	**Measure**	**Monitor**	**Change or Reconditioning**
Depletion	D5185 or ASTM D6595		Condemning limits	Condemning limits

SUMMARY

Increased contaminants, change in lubricant physicals and additive depletion are what to look for when evaluating whether or not gear oils need to be condemned and changed out. It is extremely important to obtain the condemning limits of the oil in use from the oil manufacturer. Applying the wrong condemning limit will cause inaccurate evaluation and skew the decision for condemning.

REFERENCES:

[1] ANSI/AGMA/AWEA 6006-A03 Standard for Design and Specification of Gearboxes for Wind Turbines, Page 74, Table F.4.

[2] Timken "Lubricating Your Bearings", USA_chap_5.pdf, Contamination section, Page 125, 2. Water and Timken Products Catalog, An Engineering, Page 151 Lubrication and Seals section.

[3] R.E. Cantley, "The Effect of Water in Lubricating Oil on Bearing Fatigue Life." ASLE Transactions, 20 (3), 244-248, 1977

[4] ASTM Designation: D892-06, Standard Test Method for Foaming Characteristics of Lubrication Oils.

[5] ANSI/AGMA/AWEA 6006-A03 Standard for Design and Specification of Gearboxes for Wind Turbines, Page 67, Section F5.3.3.2, Effects of Water Contamination.

[6] International Standard ISO IEC 64100-4-2012, page 136 Table E.7 Guidelines for Lubricant Parameter limits.

WIND TURBINE GEAR OIL FILTRATION PROCEDURES

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PURPOSE AND SCOPE

This Recommended Practice is for full-flow gear oil filters installed in wind turbine gearboxes. Flushing filters, and off-line (a.k.a. kidney loop) filters that may also be used with these gearboxes are defined but not discussed further in this Recommended Practice. Water and other types of contaminants are not discussed in this Practice.

INTRODUCTION

Full-flow filters are used to protect gearbox mechanical components from particle contamination suspended in gear oil. The major sources and types of particle contamination, along with associated wear mechanisms, are compiled in Table A. The most contaminant sensitive gearbox components are bearings, followed by dynamic seals, pumps, and gears. One study by Timken established gear tooth wear debris as causing the greatest damage to rolling bearings [1]. In a second study, NASA found increases in rolling bearing life up to 6 times with increasing oil cleanliness maintained with highly efficient filters [2].

Table A: Damaging Contaminant Particles Found in Wind Turbine Gear Oil.

Sources/Ingression	Types	Wear Mechanisms
airborne mineral dusts	vents, ports, seals	sliding contact abrasion in gears, seals, pumps, retainers
metallic wear debris	gear tooth wear	rolling contact fatigue leading to pitting, spalling
manufacturing swarf: polishing/lapping grits; metallic chips	new installations, replacement parts	early failures of bearings, pumps, seals, gears
salt	marine sea spray followed by airborne ingression	corrosion

FULL-FLOW GEAR OIL FILTER PROCEDURES

1. TARGET PARTICLE CONTAMINATION LEVELS

In order to minimize damage to gearbox components, it is recommended gear oil be maintained at specified levels of cleanliness, or better. Quantities of particle contamination measured in oil samples are typically reported according to ISO 4406[3]. This format reports the number of particles per milliliter equal to or greater than a given size, in micrometers (µm). Particles per milliliter greater than 3 sizes are reported:

1 ≥ 4 µm

2 ≥ 6 µm

3 ≥ 14 µm

The number of particles for each size range is reported as an 'ISO Code'. For example, the number of particles in a particular sample of gear oil is reported as: ISO 19/17/15.

This translates to:

1) 19: 2500-5000 particles/mL ≥ 4 µm in size

2) 17: 640-1300 particles/mL ≥ 6 µm

3) 15: 160-320 particles/mL ≥ 14 µm

An increase of one ISO Code equates to an increase in particle contamination by a factor of 2. As a second example, an oil sample with an ISO Code of 20/18/16 has in each size range two times more particles than the previous example. Maximum particle contamination levels are specified by gearbox or turbine manufacturer, or by in-house specification. Table 17 of ANSI/AGMA/AWEA 6006-A03[4] (See Table B) suggests a set of maximum allowable contamination levels for wind turbine gearboxes. ***Turbine or gearbox OEM, or in-house specifications, take precedence over this table.***

Table B: Lubricant Cleanliness.

Source of Oil Sample	**Required Cleanliness Per ISO 4406**
Oil added into gearbox at any location	- / 14 / 11
Bulk oil from gearbox after factory test at the gearbox manufacturer's facility	- / 15 / 12
Bulk oil from gearbox after having been in service 24 to 72 hours after commissioning of the WTGS (pressure fed systems only)	- / 15 / 12
Bulk oil from gearbox sampled per the operating and maintenance manual (pressure fed systems only) *(See Step 6.7.)*	- / 16 / 13

Particle contamination in operating systems may be monitored by two alternative approaches:

This translates to:

1. Periodic oil samples are obtained from the gearbox then sent to a laboratory for analysis. This is the method currently used by a large majority of operators.

2. An on-line particle counting unit mounted on the gearbox. This has the advantage of providing real-time data. ***Disadvantages are unit and installation costs; maintenance and that the sensor technology is not as accurate as a commercial testing lab at this point in time.***

2. SELECTING FULL FLOW GEAR OIL FILTERS

2.1. Definitions

2.1.1. Full-flow filters receive the total flow of lubricant produced by the main lubrication system pump(s). All suspended particles in the oil reservoir are carried by the flowing gear oil into these filters. Depending on filter efficiency (filter rating), many to most damaging particles are removed from the gear oil by the full-flow filter before reaching loaded mechanical components, especially bearings and gears.

2.1.2. Off-line filtration systems are designed to operate independently of, or in addition to, the full flow filtration system. Off-line filtration may be used to supplement contaminant removal by full-flow filters, if deemed necessary to meet specified cleanliness levels.

2.1.3. Flushing filters are used to clean a gearbox during an oil change or after a system upset. These filters are temporarily plumbed into the gearbox lubricant system, and removed when the clean-up is completed. Flushing filter ratings should be as good as or greater than the full-flow filters installed on the gearbox.

2.2. Full-Flow Filter Ratings

The function of a full-flow filter is to remove damaging particles from the lubricant. For modern industrial filters, particle removal efficiency (a.k.a. filter efficiency) is reported as a 'filter rating'. Examples are filters rated at 5 µm or 10 µm. For particles this size and larger the filter is extremely efficient, as determined and quantified by laboratory testing. As illustrated in Figure 1, filter efficiency is determined by ISO 16889(5). (See Figure 1.)

2.2.1. The procedure is performed under controlled laboratory conditions.

2.2.2. A slurry of test dust (finely powered silica sand) in oil is flowed into the filter.

2.2.3. The number of particles entering and leaving the filter are sized and quantified throughout the test using electronic particle counters.

2.2.4. Filter ratings are reported as beta ratios: ß10(C) = Number Particles Upstream ≥ X µm ÷ Number Particles Downstream ≥ X µm

2.2.5. For example, a filter rated at 10 µm has ß10(C) ≥ 1000.

2.2.6. Not all filters are equal. For example, a filter rated at 5 µm is 20 to 50 times more efficient at removing particles than a 10 µm filter, which in turn is 20 to 50 times more efficient than a filter rated at 20 µm.

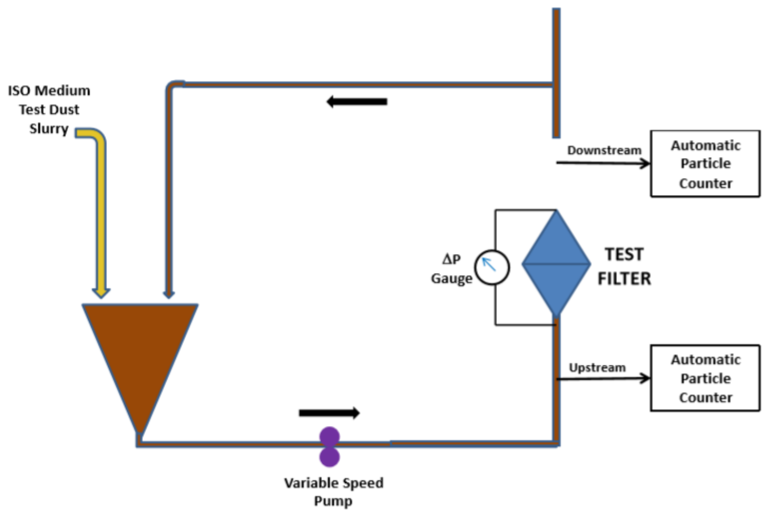

Figure 1. Multipass Test Per ISO 16899

2.3. Proper Filter Performance Parameters

Several additional parameters are required to ensure proper filter performance in a gearbox:

2.3.1. Differential Pressure (ΔP)

Filters present restrictions to flow. As gear oil flows through the filter, differential pressure (ΔP) develops across the filter. Differential pressure increases with increasing flow rate and oil viscosity. Cold gear oil flowing through a filter, such as during a system cold-start, often produces the greatest differential pressure experienced by full-flow filters. A maximum differential pressure may be specified by the gearbox or turbine OEM for unused filters at specific flow rates, oil types, and temperatures.

2.3.2. Compatibility and Integrity

The full-flow filter must be able to maintain integrity and withstand maximum differential pressure (including during cold-start) after contacting gear oil at highest system temperature. For additional information, see ISO 2941, "Verification of Collapse Burst Pressure Rating", and ISO 2943, "Filter Elements - Verification of Material Compatibility with Fluids".

2.3.3. Filter Service Life

As filters capture and retain particles, flow restriction and differential pressure increases. Full-flow filters are changed at or before a maximum differential pressure are reached. This ΔP value is specified by the gearbox or turbine manufacturer. The time interval between installation and removal is termed the filter service life. The ISO 16889 Multipass Test measures dirt holding capacity of silica sand under controlled conditions. However, because different types of contaminants load filters during field operation, this test method may not accurately predict the service life of full-flow filters in wind turbine gearboxes. It is recommended service life be established by field experience and evaluations.

2.4. Selecting a Full-Flow Filter

The full-flow filter should meet or exceed the specifications of the gearbox and/or turbine manufacturer. The filter rating should be sufficient to meet or exceed target cleanliness levels under real-world operating conditions. For concerns with possible removal of additives, confer with the oil supplier.

3. CHANGING SPENT GEAR OIL FILTERS

Two strategies are used for changing spent full-flow filters. The strategy used at a specific site may be specified by the gearbox or turbine manufacture, or by an in-house specification.

3.1. On-Time

This is the strategy used by the majority of wind turbine operators. Full-flow filters are changed at a convenient service interval. Currently, the most common service interval for land-based turbines is 6 months. Because filters are expected to last a minimum of 6 months, many are changed before dirt holding capacity has been depleted.

3.2. On-Condition

Full-flow filters are changed when a differential pressure indicator signals at predetermined value of ΔP. This change-out ΔP is set below the differential pressure that activates the by-pass valve, avoiding unfiltered lubricant passing into the gearbox. Because the maximum dirt-holding capacity of the filter is used, this method tends to increase filter change-out intervals. However, tower climbs at irregular intervals to change these filters may be inconvenient and/or uneconomical.

4. FILTER CHANGE-OUT CHECK LIST

______ 1. Down Tower Inspect new filter. There should be no damage from handling/shipping.

______ 2. Bring Up Tower Plastic waste bag for used filter. If changing spin-on filter, bring belt wrench. 2 gallons of pre-filtered make-up gear oil.

NOTE: The rating of the filter used for pre-filtering the gear oil should be at least as fine as the filter installed in the gearbox.

______ 3. If Changing a Cartridge Filter Remove cover from housing. Partially remove used filter and let drain for several minutes. Completely remove used filter and place in plastic waste bag. Install new filter into housing. Secure cover onto housing and tighten fittings. Top up oil as needed.

______ 4. If Changing a Spin-On Filter Remove old spin-on; may need belt wrench. old spin-on filter into plastic waste bag. Spin new element onto filter head and tighten. Top up oil as needed.

______ 5. When Back down Tower Discard used element according to company policy.

SUMMARY

By protecting contaminant sensitive components from harmful particles, full-flow gear oil filters are indispensable for achieving acceptable uptime and life of wind turbine gearboxes, as well as for reducing maintenance costs. The full-flow filter installed on the gearbox should meet or exceed specifications. Specifications include but are not limited to filter rating (particle size where ß X(C) ≥ 1000), differential pressure (ΔP), compatibility, and integrity. The filter should also provide an acceptable service life, based on the needs of the site. A checklist is included to aid the proper change-out procedure when replacing spent filters with new filters.

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[5] ISO 16889:1999, "Hydraulic Fluid Power Filters - Multi-pass Method for Evaluating Filtration Performance of a Filter Element."