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Oil Analysis

Oil Analysis Improves Wind Turbine Gearbox Performance - Part 1

Whitepaper

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Introduction

Within the current environment of renewable energies, wind energy has played an important role as a driver of change in the generation of clean alternative energy. However, this rapid increase has given rise to several operational and performance issues related mainly to equipment design and maintenance practices.

Figure 1 - Typical wind turbine environment

The adequate functioning of a wind turbine depends to a large extent on the performance of the gearbox. These gearboxes have planetary gearsets and bearings that require special attention due to their extreme operating conditions (temperature, environment, etc.). Under these conditions, oil analysis and wear particle analysis are far more effective predictive/proactive tools for achieving optimum machine performance.

Figure 2 - Gear teeth in a wind turbine gearbox

This white paper will address how oil analysis can identify and correct the main problems associated with wind turbine gearbox maintenance. These problems include micropitting, air or foam in the oil and adequately estimating the remaining useful life of the lubricant.

1. Selecting A Gearbox Oil

Selecting and maintaining the proper oil is key to optimal gearbox operation and should be a shared responsibility between user, OEM, component manufacturer (bearings, etc.) and oil and filter suppliers.

To handle extreme load and speed variations, wind turbine gearbox oils often include extreme pressure (EP) additive packages.

The base fluids used can be mineral or synthetic. The mineral fluids are products derived from petroleum, while the synthetic fluids are produced through synthesis.

The synthetic oils can be: Polyalphaolefins (PAO), Ester oils (E) or Polyglycols (PAG).

The properties of a new oil for wind turbine gearboxes must be in accordance with German standard DIN 51517 Part 3, and with the following requirements:

Parameter	Methodology	Criteria
Viscosity index	ISO 2909	Minimum 90
Oxidation stability	ASTM-D2893-Amended	Increase in viscosity to 121°C < 6%
Corrosion of steel	ISO7120	Negative
Corrosion of copper	ISO2160	<1B
Foam	ASTM-D892	75/10 75/10 75/10
FZG Scuffing	ISO 14635-1	>=12
Micropitting	FVA 54	>=10
Filterability	AFNOR NF E48690 5 Microns	Pass
Cleaning	ISO 4406/99	16/14/11
FE 8	DIN 51819	<30 mgr /80 h
Brugger	DIN 51347	> 50 N/mm2
Air retained at 90°C	ASTM-D 3427	< 15 minutes
Weld load	ASTM-D 2783	>250 Kg
Wear 1800rpm/20kg/54°C/60min		< 0.35 mm
Demusibility 82°C	ASTM-D1401	< 15 mins

Figure 3 - Recommended wind turbine gearbox oil performance test package

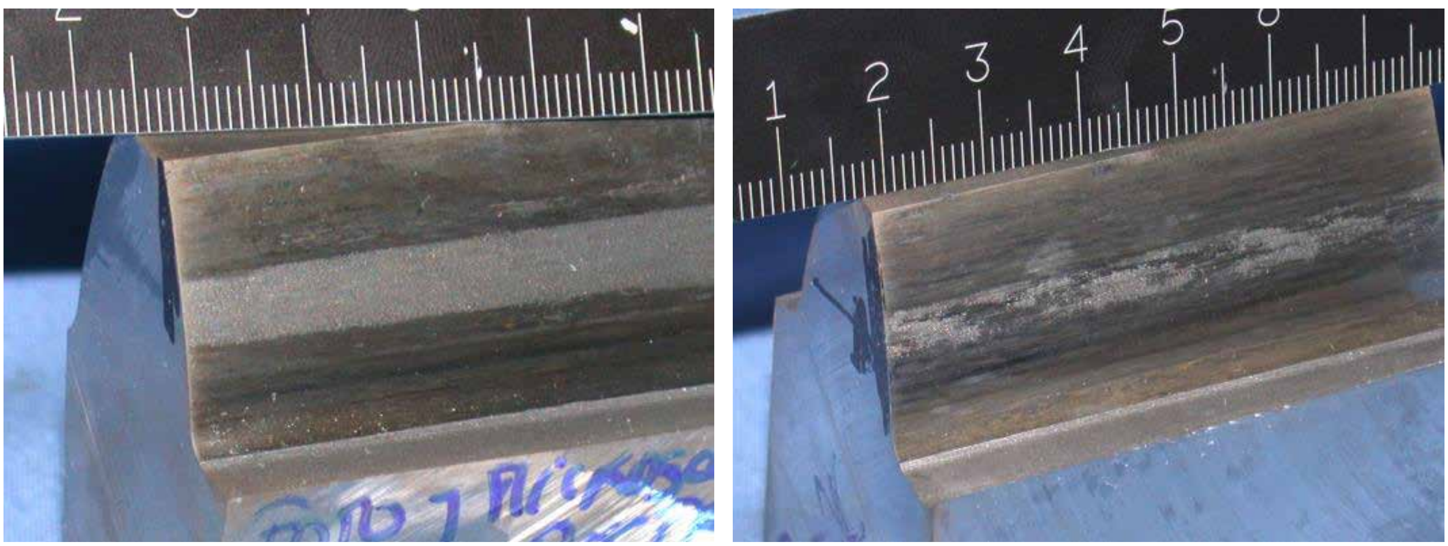
2. Problems With Gearbox Oils

The main issues oil analysis identifies in gearbox lubricants are:

- Micropitting (Wear Debris)
- Foam and retained air
- Accurate measurement of the oil's remaining useful life

2.1. Micropitting

Although micropitting is not a new phenomenon, it has not been given much significance until now. However, it is known to affect gear-tooth precision and, in many cases, it is the first type of fault. Micropitting is a surface fatigue phenomenon that occurs in Hertzian contacts, caused by cyclic contact stress and the plastic flow of asperities. This results in the formation of microcracks and micropitting and loss of material. Micropitting is also referred to as fatigue scoring, flecking, spalling, glazing, frosting, grey staining, microspalling, peeling, etc.



Figures 4 & 5 - Gear teeth with micropitting along the load-bearing surface of the gearbox gears

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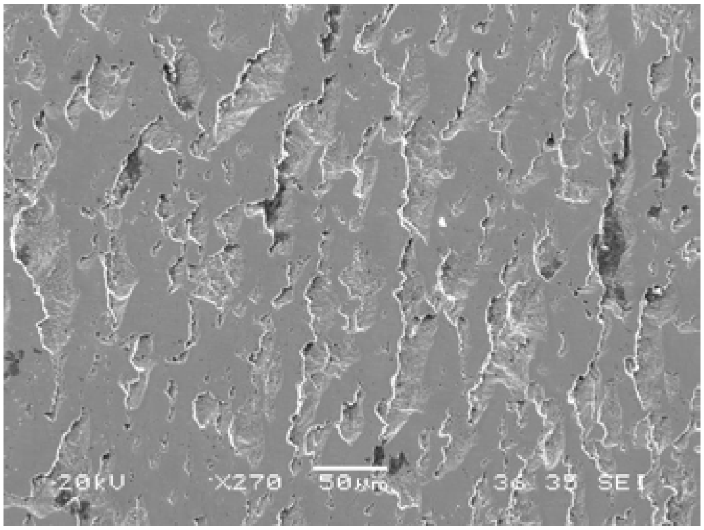

Figure 6 - Micropitting on a gearbox gear obtained using an SEM

Micropitting is surface damage which occurs in high load-bearing systems and is characterised by the presence of small holes in the surface, revealing an inner surface with cracks. It first appears on the load-bearing surface and then extends towards the root (dedendum) of the tooth, the area where the gear works harder.

All gears are susceptible to micropitting, including external, internal, spur, helical, and bevel gears. Micropitting can occur in heat-treated materials, including nitrided, hardened, tempered, etc.

It is still not fully understood why some oils are more prone to the formation of micropitting than others.

Micropitting results in the loss of tooth profile and could potentially lead to macropitting, breakage of the tooth, noise and vibration.

While both are the result of metal fatigue, micropitting is much smaller than macropitting. Metallographic analysis shows that the cracks in both have the same morphology but are a different size.

Micropitting is not considered to be a problem in itself, but it can sometimes lead to macropitting. This is a failure caused by surface roughness and not Hertzian contact stress. Greater roughness produces greater stress under the surface, which results in micropitting.

In many cases micropitting is not harmful to the gear surface, and its development may even be stopped when the tribological conditions of the system are re-established. Micropitting can be sometimes be eliminated by polishing during the gear rolling process, when it is said that the gears have been ‘cured’. The depth of micropitting is no greater than 10 microns and is difficult to see with the human eye, only becoming perceptible when measuring more than 40 microns.

There are few micropitting control methods currently in use. The main methods are visual inspections (borescope), oil analysis and destructive testing of gears. The resistance of new oils to micropitting is evaluated using the high-speed gear test, for example, the FZG FVA54 I-IV micropitting test and the BGA micropitting test.

2.1.1. Where to look?

Visual inspections offer a good method of controlling micropitting in in-service gears. The appearance is a change in the tone of the gear - dull, grey - and is difficult to see.

Micropitting starts on the load-bearing surface and is mainly due to asperities remaining after the manufacture of the gears. This is why this phenomenon usually appears at the beginning of the machine's life, during the first million gear cycles.

Visual inspections offer a good method of controlling micropitting in gears in service.

The appearance is a change in the tone of the gear - dull, grey, etc. It is difficult to see.

Micropitting begins as a surface contact at the edges of the gears where there are crests, undulations, peaks, etc. It is usually accompanied by other failure modes such as scuffing, macropitting and abrasion.

When the damage caused by micropitting varies from tooth-to-tooth it is mainly because of variations in tooth geometry or surface roughness. The micropitting pattern on a gear set may repeat at a particular frequency of a common factor. For example, a gear set with a 20/45 tooth combination may display similar micropitting on every fifth tooth.

2.1.2. What causes micropitting?

Micropitting occurs under elastohydrodynamic lubrication (EHL) where the thickness of the lubricant film is of the same order as the composite surface roughness and the load is borne by surface asperities and lubricant. Under elastohydrodynamic lubrication (EHL) the lubricant almost solidifies, depending on the type of lubricant.

Incubation: The incubation period occurs with the plastic deformation of surface asperities, and cyclic contact and stresses accumulate plastic deformation and initiate fatigue cracks. **Nucleation:** After fatigue cracks appear, they grow and coalesce. The resulting pit can be up to 10 microns, imperceptible to the human eye. The particles generated by micropitting are of the order of one micron or smaller, up to 10 or 20 microns. It is usually not possible to eliminate these particles with strainers and they act by polishing the gear surface. Polishing wear is often found when micropitting is present.

2.1.3. Effect of lubricants

Lubricant properties, the base oils used, additive chemistry and viscosity all affect micropitting. Micropitting tests show that resistance to micropitting varies from one lubricant to another. Some lubricants are capable of halting the process once it has started. Some lubricants are capable of halting the process once it has started.

2.1.3.1. Base oils

Lubricants solidify under the high pressure generated in elastohydrodynamic lubrication (EHL) conditions, and tractional stress on the surface asperities is limited by the rupture stress of the solidified oil. There are considerable differences between the solidification pressure and the rupture stress of different lubricants, and hence differences in their tractional properties.

Polyglycols and esters have molecules with flexible ether linkage and a lower rupture stress value than hydrocarbons. Naphthenic oils are relatively rigid, compact molecules that generate high traction, while paraffinic oils and polyalphaolefins (PAOs) have open, elastic molecules with a low traction coefficient. PAOs and non-conventionally refined oils have less traction coefficient than solvent-refined oils. Many PAOs are blended with esters to increase solubility for additives. Unfortunately, esters are very hygroscopic and so the micropitting resistance of the PAOs may decrease significantly.

Micropitting occurs with both mineral and synthetic oils. At high temperatures, PAO and PAG synthetic oils have thicker EHL films, and therefore greater resistance to micropitting than mineral oils with the same viscosity grade and additives. At temperatures ranging from 70°C to 90°C little difference exists between the mineral oils and the PAOs, whereas PAG lubricants have thicker films.

2.1.3.2. Additives

Anti-scuffing (EP) additives are normally necessary but can be chemically aggressive and may promote the appearance of micropitting. Oils without anti-scuffing additives provide maximum protection against micropitting.

Experiments show widely varying, and sometimes conflicting, results regarding the influence of EP additives on the onset of micropitting. Some tests show that oils with additives containing sulphur and phosphorus (S-P) promote the appearance of micropitting while other tests show that these additives increase resistance to micropitting.

The additive activation temperature may be one of the reasons for these conflicting results. If tests are performed at different temperatures, the performance of the additives will be different. Therefore, all micropitting tests should be conducted at a temperature closest to the operating temperature. The generally accepted test is the FVA 54, performed at 90°C, and lubricant manufacturers increasingly characterise the oil at 60°C.

EP additives can react with the tooth surface reducing its resistance to surface fatigue making them unsuitable alternatives. So as to not significantly affect lubricant performance, additive levels should be no lower than 50% of the value of the new oil.

2.1.3.3. Viscosity

Low viscosity oils reduce film thickness which in turn promotes the propagation of cracks. High viscosity oils provide greater resistance to micropitting because of the thicker film, and are therefore less likely to promote the propagation of cracks. However, viscosity must be limited since excessively high viscosity can promote oxidation of the oil, loss of energy, more residue, etc.

However, viscosity should be carefully calculated in order to protect the components from all kinds of problems. Variations in the viscosity above 10% with respect to the value of the new oil should not be permitted.

The influence of additives can ruin the effect of viscosity. Therefore, increasing the viscosity will not eliminate micropitting if the base oil contains aggressive additives.

2.1.3.4. Particles

Solid particles in the oil that are larger than the EHL film can enter between the gear teeth due to the rolling action. Once they enter, they are subject to high pressure levels. The particles are brittle and break up into smaller particles, some becoming embedded between the gears and others passing through the contacts. Hard particles larger than the film thickness can pass through the contact.

The small particles that enter the contacts cause dents in the gears and promote the formation of micropitting.

Particles that have not been removed in the manufacturing process must be eliminated immediately by filters. It is very important that the oil is clean when incorporated into the machine.

Oil Sample	Cleanliness ISO 4406/99
New oil	16/14/11
From gearbox after manufacturing	17/15/12
From gearbox during service	18/16/13

Figure 7 - ISO cleanliness levels throughout useful life of the oil

2.1.3.5. Water

Many experiments have shown that oil in the water promotes wear. Hydrogen blistering and embrittlement (a phenomenon caused by hydrogen atoms entering the cracks and fissures of the material, forming hydrogen molecules or combining with a metal) may produce a failure. The maximum water content admissible in gearbox oil must not be over 200 ppm.

2.1.4. Elastohydrodynamic (EHL) lubrication

The film thickness of the oil is determined by the oil's response to the shape, viscosity and velocity of the contact inlet. Higher load causes increased elastic flattening without producing significant changes in the inlet geometry. Therefore, film thickness is insensitive to the load and elastic properties of the material.

In contrast, the film thickness is highly influenced by the entrance speed of the oil and by its viscosity. It is also highly dependent on the gear temperature, but not on the higher flash temperature, which usually occurs in the central region.

The central region of contact is relatively long. Once inside the central region, the oil can not escape because of its high viscosity, the gap is small and the time of contact very short. Generally, all the oil that enters goes through the contact area as a solid sheet of uniform thickness. On exiting, the oil reverts to its atmospheric properties.

3. Operating parameters to control micropitting

3.1. Load

Load does not have a major influence. High loads do not mean that micropitting will occur in the gears. Dr. Andy Olver (Imperial College) reports that the formation of micropitting is influenced by the load. However, Robert Errichello has not found a direct relationship.

3.2. Velocity

Rolling velocity is very important and beneficial since it increases the entry speed of the lubricant, promoting the formation of films and reducing the influence of the asperity contact. Sliding speed, on the other hand, generates heat and increases the formation of particles.

3.3. Temperature

The temperature is critical to film thickness and the activation of the lubricant additives. The equilibrium temperature is established by the balance between the heat generated by friction and the heat dissipated by conduction and convection. The temperature of high-speed gears can be much higher than the temperature of the oil supplied to the gears.

Micropitting resistance decreases with higher gear-tooth temperature. However, the performance of some additives improves with higher temperatures. This is very important when establishing temperatures in laboratory micropitting tests.

4. Conclusions

Micropitting can be prevented by maximising film thickness, reducing surface roughness (coating the gears, etc.) and optimising the properties of the lubricant by avoiding aggressive EP additives, maintaining proper lubricant cleanliness levels throughout useful life and using lubricants with a low traction coefficient, etc.

First, and foremost, select the proper lubricant and keep it clean. dry and at optimum operating temperature while in use.

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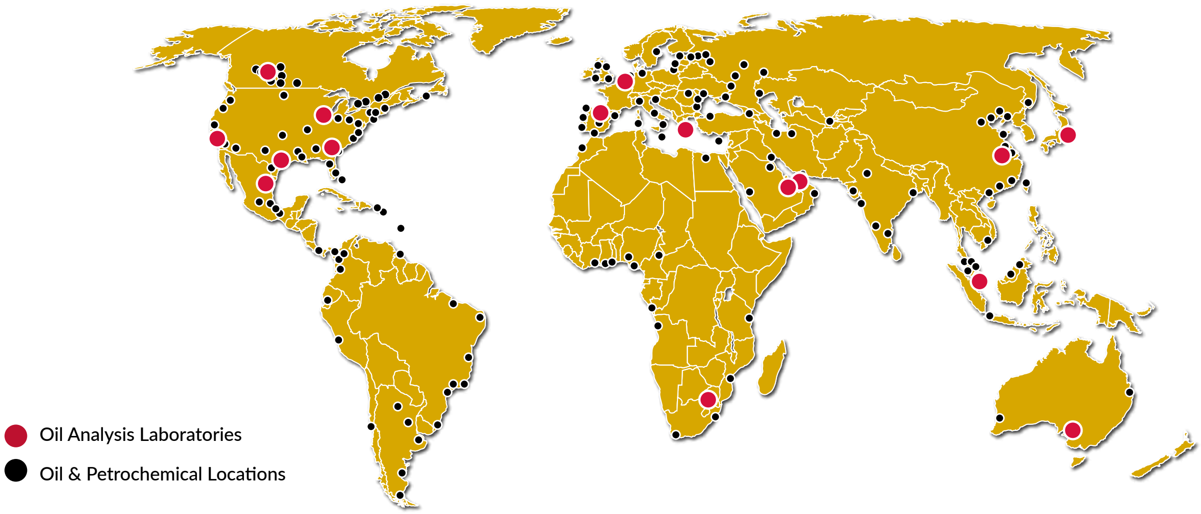

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