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Title: Extending the scope of gearbox oil condition monitoring for wind turbines: Identified challenges and recommendations

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Introduction

In recent years the increased size of wind turbines and the installation of offshore wind farms encouraged the implementation of condition-based maintenance to reduce the operation and maintenance costs of wind energy projects. In order to achieve an effective maintenance, condition monitoring systems (CMS) have been integrated in modern multi-Megawatt wind turbines, where vibration-based CMS are the preferred choice for monitoring the drivetrain condition [1] [2] [3]. In the case of geared wind turbines, oil condition monitoring (OCM) facilitates the identification of wear-related damage and degradation processes in the oil. Therefore OCM provides valuable information about the gearbox condition in order to extend oil change intervals or identify wear related damage by means of particle counting [4] [5].

The most common practice in the wind industry is the extraction of oil samples for laboratory analysis. As oil sampling is an offline method, it is important to consider that the results represent only a specific point in time. These results can be influenced by the sampling procedure, the oil temperature, the positioning of the sampling valve, the laboratory performing the analysis among others [6] [7]. Online condition monitoring, in contrast, allows a continuous observation of the oil condition by means of oil sensors. However, the parameters that can be observed in this way are reduced in comparison to a laboratory analysis. These do not include e.g. additive concentration, Total Acid Number (TAN) or absolute water content.

As the implementation of oil sensors for OCM is in an early stage, this paper presents the results of a testing campaign on an oil sensor test bench. During this testing campaign, several types of sensors including particle counters, oil properties sensors and water content sensors are tested under several operating conditions. The results of this study show the limitations and advantages of offline and online OCM methods, which allows giving recommendations on the choice of oil sensors. Oil aged in a laboratory and oil extracted from wind-turbine gearboxes in the field are used to perform the tests and provide a deeper understanding of the oil aging process occurring in wind turbines.

Approach

Oil sensor testing

In order to assess the capability of online and offline OCM methods, namely oil-sensor and oil-sample-based monitoring, an oil sensor test bench, which is described in [8], is designed. The oil sensor test bench allows analyzing the detection capability and quality of different types of sensors. This is achieved due to the well defined and reproducible operational characteristics of the test bench. The main goal is to test sensors with aged oil, water, foaming and particle contamination with reproducible test procedures. The oil sensor test bench consists of an oil circuit in which several sensors can be installed in horizontal and vertical position. Several adapters are used to install the sensors in different positions in the test pipe. The test bench has a heat exchanger to control the oil temperature. A contamination unit with a rotor-stator system for homogenization is used to artificially contaminate the oil with particles or water. The test bench is illustrated in Figure 1.

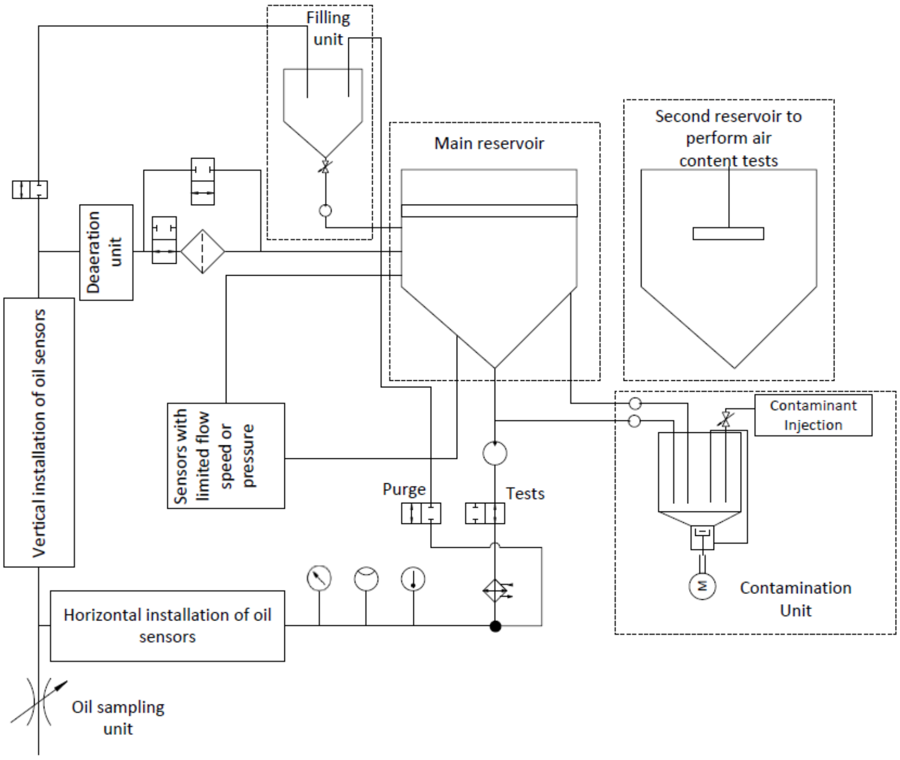

Figure 1: Oil sensor test bench layout

Among the possible testing scenarios, this paper includes a stepped temperature profile ranging from 40°C to 80°C. Additionally, tests with contaminated oil containing particles of sizes below 100µm are carried out at 60°C with a constant volume flow rate of 10l/min, as illustrated in Figure 2.

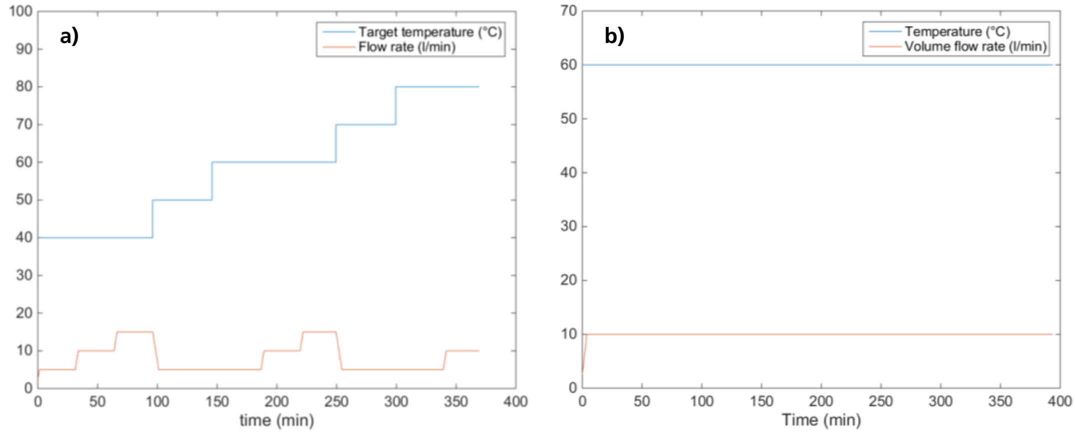

Figure 2. Test profiles: a) Temperature step profile. b) Constant temperature profile used for tests with particle contamination

The sensors used in these tests are listed in Table 1. For further information about the sensors, the reader is referred to [1].

Table 1. Sensors under test on the oil sensor test bench

Type of sensor	Number of sensors	Positioning
Temperature sensor	3	Horizontal pipe, main reservoir, contamination unit
Water-content sensor	2	Horizontal and vertical pipe
Oil-properties sensor	2	Horizontal and vertical pipe
Wear-debris sensor	2	Horizontal and vertical pipe
Particle-concentration sensor	1	Parallel pipe connected to the main reservoir

Oil aging

In order to take into account the changes in the oil properties and perform a corresponding analysis, a thermal oxidative oil aging process for a common gearbox Poly-alpha-Olefin (PAO) oil is performed in the slave gearbox of a FZG-back to back test rig [9] at the Gear Research Centre (FZG) of the Technical University Munich. This oil aging process provides information about the degradation of the gearbox oil. Fresh oil is aged before testing in two different stages based on changes on additive concentration, TAN or viscosity. In collaboration with an oil analysis laboratory and the FZG, the oil aging stages have been defined as described in Table 2.

Table 2. Parameters defining the condition of aged oils

Aging Stage	Description	Changes in TAN	Changes in kinematic viscosity	Changes in the additive concentration
Aging Stage I	aged, but suitable for further use	Minimum increase of 0.3 mgKOH/g	5 % - 10%	decrease of additive concentration of >10%
Aging Stage II	aged and deteriorated, not suitable for further use	Minimum increase of 0.5 mgKOH/g	>10 %	decrease of additive concentration of >20%

The oil aging is usually carried out at a temperature of 120°C. For accelerating the aging process, the oil temperature can be increased up to 135°C.

Results and discussion

Oil sensor testing

The test with the temperature step profile from 40°C – 80°C shows that the water saturation level measured by the water content sensors and by the oil properties sensors differs by around 5%. The measurements depend on the oil aging stage, the type of sensor and their positioning as illustrated in Figure 3.

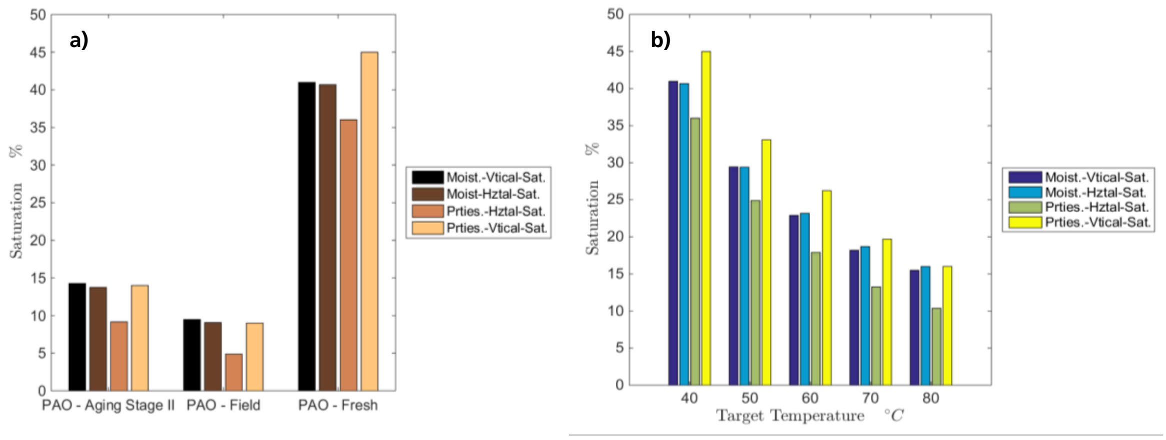

Figure 3. Water saturation levels measured by water-content sensors and oil-properties sensors in horizontal and vertical position: a) Test with oils in different aging stages at a temperature of 40°C, b) Test with fresh PAO at different temperatures

The absolute water content of the oils was determined by Karl-Fischer-Titration. This offline measurements lies between 30 – 70 ppm. These results do not correlate with the sensor online measurements by comparing the results using a saturation curve provided by the oil manufacturer.

During the contamination test profile at constant temperature of 60°C, oil-particle mixture with sizes <100µm corresponding to a particle concentration of approximately 300 ppm and 600ppm were recreated. Oil samples were taken at three occasions and were analyzed in a laboratory. The results are compared to the sensor online measurements recorded at the same points in time, see Figure 4. The results show the increased contamination and the difference between online and offline measurements.

Changes in the dielectric constant and the conductivity due to oil aging and additive depletion as well as tests with different particle sizes and oil from the field will be presented in the full paper.

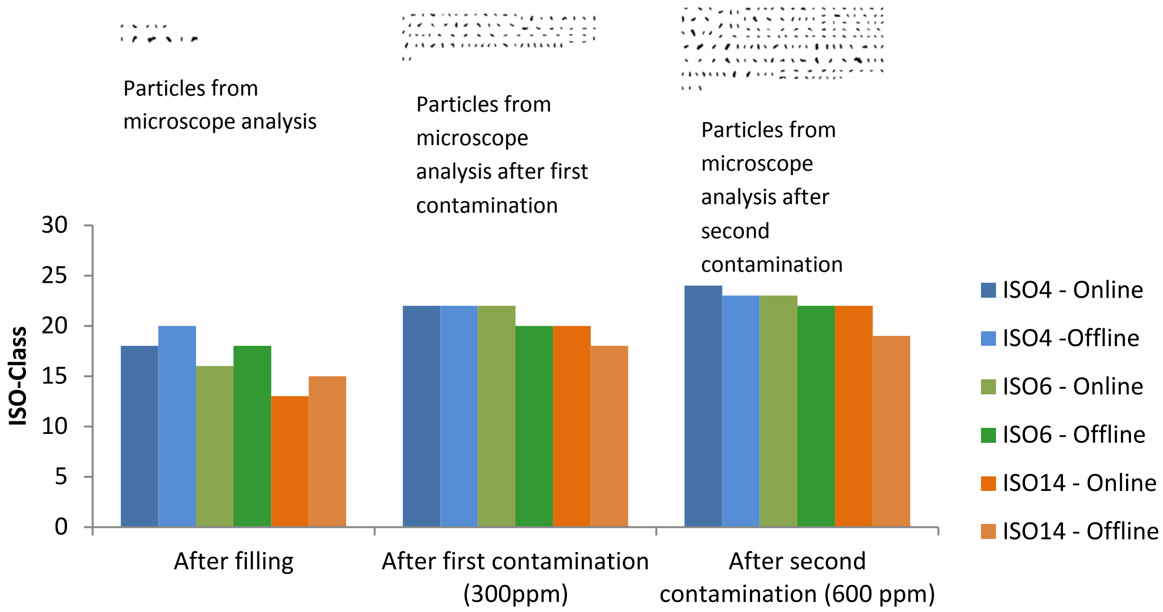

Figure 4. Offine and online particle concentration measurements and corresponding microscope analysis results

Oil aging

The results of the thermal oxidative aging indicate that the TAN decreases in the initial aging phase and increases almost until the end of the aging procedure. After 798 hours the TAN increased by 0,54 mg/KOH/kg. Furthermore, this aging includes significant decrease of the Phosphor and Sulphur. This indicates a decomposition of (anti-wear-) additive components. In combination with the results of further investigations, like the infrared-spectroscopy and an evaluation of the development of the kinematic viscosity, the lubricant can be regarded as an aged lubricant. A detailed analysis of this oil aging will be presented in the full paper.

Conclusions

The study shows that particle counting results obtained with online methods differ from those of oil-sample based offline methods. Both methods can be implemented to monitor oil quality, but the online measurements should be compared with oil sampling. The water saturation levels are found to be influenced by the aging stage, the sensor type and its positioning. In addition, considerable deviations of the sensor measurements from offline-analysis results of the water content are observed. These findings emphasize the importance of verifying the sensor accuracy before application in wind turbines. Further analysis concerning the measurements of wear debris, dielectric constant and conductivity will be illustrated in the full paper.

Learning objectives

The main objectives of this talk / paper are:

- Insight about oil parameters to monitor oil degradation of wind turbine gearbox oil by offline and online condition monitoring approaches
- Introduction of an assessment method to verify the detection capability of oil sensors
- Identification of changes in key properties of the oil as a function of aging temperature and time

Abbreviations

CMS	Condition Monitoring Systems
FZG	Gear Research Centre
OCM	Oil Condition Monitoring
PAO	Poly-Alpha-Olefin
TAN	Total Acid Number

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