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EXPERIMENTAL RESULTS OF DIFFERENT OIL CONDITION MONITORING APPROACHES FOR WIND TURBINE GEARBOXES IN AN OIL SENSOR TEST BENCH

TRACK OR CATEGORY

Wind Turbine Technology II

AUTHORS AND INSTITUTIONS

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INTRODUCTION

The need for reduction of operation and maintenance costs of multi-megawatt wind turbines has driven the implementation of Condition Monitoring Systems (CMS) to perform condition-based maintenance. As described in [1], vibration-based and oil-based CMS are the most common approaches implemented for the drive train in wind turbines. Vibration-based CMS are standard solutions, which can be certified facilitating their assessment regarding effort of implementation, data collection and interpretation [2] [3]. In the case of oil-based condition monitoring, oil sampling is the current method used in wind turbines. This offline approach gives detailed information about the oil properties being essential to determine if an oil change is necessary due to oil degradation or contamination. However, the results of oil sampling can be influenced by the sampling procedure, the oil temperature, the positioning of the sampling valve and the cleanliness of the sampling bottle. For online oil-based CMS, several sensors can be used to monitor different oil parameters as described in [1] [4]. Previous studies emphasize the importance of testing sensors before their application in the field. Such tests can provide useful information concerning the functionality of the sensors during different operating conditions and under the influence of foam generating an air-oil-dispersion or contaminants e.g. water or particles [4] [5] [6]. This paper presents the first results of a testing campaign on an oil sensor test bench. During this testing campaign, several types of sensors for wind turbine gearboxes including particle counters, oil-properties sensors and water content sensors are tested under several operating conditions. The effects of oil temperature as well as of water and particle content in the oil are analyzed to assess the detection capability of the sensors. During this testing campaign, one oil type in two oil aging stages is analyzed. Finally, a comparison between sensor-based and sampling-based oil condition monitoring is presented.

TEST METHOD

An oil sensor test bench has been developed at Fraunhofer IWES to validate sensors for wind turbine gearboxes, as illustrated in Figure 1. The oil sensor test bench consists of a main reservoir and a test pipe where several sensors can be installed in horizontal or vertical position. A heat exchanger controls the oil temperature of the oil circuit. A contamination unit equipped with a rotor-stator system allows the homogenization of water-oil emulsion and oil-particles suspensions, which can be fed into the main circuit by means of a peristaltic pump. An alternative reservoir can be used for testing the sensors under the effect of air-oil-dispersion by means of Flender gears, which allows the generation of foam. The operating parameters which are considered to perform different test scenarios in the test bench are described in [6].

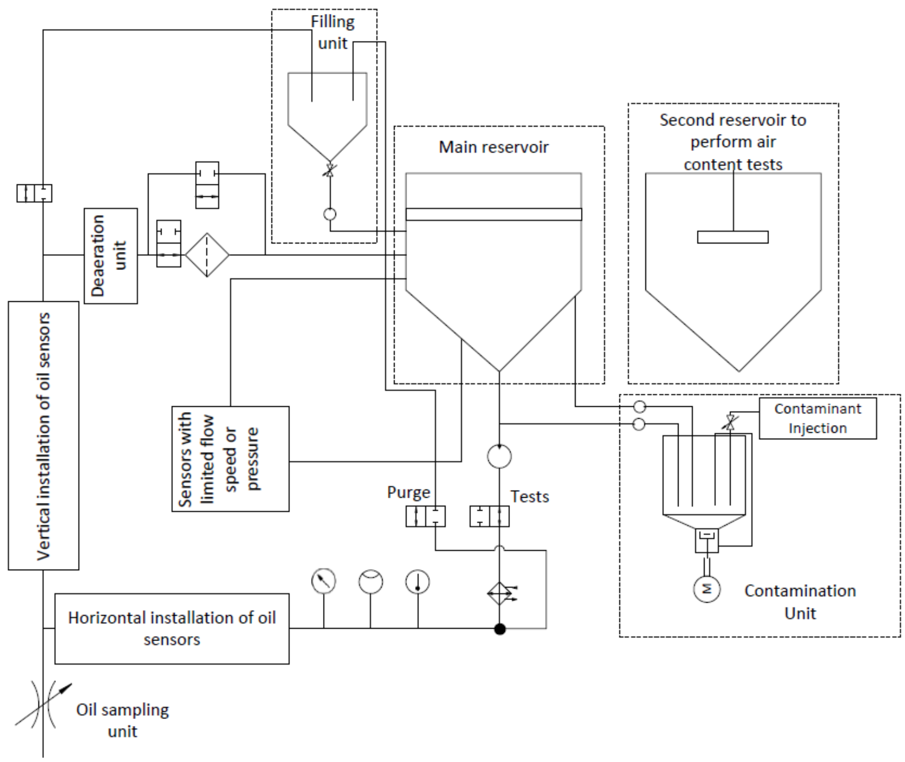

Figure 1: Oil sensor test bench layout

For this testing campaign, a poly-alpha-olefin (PAO) oil with a viscosity grade of 320 is used. The main objective of the tests is to compare the sensor measurements in different oil aging stages in order to identify possible changes on the sensor output signals due to oil aging. A sample of the same PAO was extracted from a wind turbine in the field to be used in the oil sensor test bench. This oil was extracted during an oil change operation, which usually takes place after three to six years. Both the fresh and the field-aged oil are used to investigate the influence of the oil degradation on the signals of the sensors. The sensors installed in the oil sensor test bench are illustrated on Table 1.

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

Type of sensor	Output signal	Number of sensors	Positioning
Reference temperature sensors	Oil temperature	3	Horizontal pipe, main reservoir, contamination unit
Water-content sensor or moisture sensors	Water saturation level, oil temperature	2	Horizontal and vertical pipe
Oil-properties sensor	Oil temperature, water saturation level, dielectric constant, conductivity	2	Horizontal and vertical pipe
Wear-debris sensor	Counting of Fe-Particles >70µm and non-Fe-particles >200µm, oil temperature	2	Horizontal and vertical pipe
Particle-concentration sensor or ISO sensor	Particle concentration according to ISO 4406, oil temperature	1	Parallel pipe connected to the main reservoir

In this paper, two test profiles are used for analyzing the sensors:

- Temperature steps from 40 to 80°C with laminar flow
- Constant temperature at 60°C with contamination of iron particles with sizes >100μm with laminar flow

For further information concerning the possible testing scenarios in the oil sensor test bench, the reader is referred to [7].

RESULTS

The temperatures measured by the moisture and oil-properties sensors during the step profile are in satisfactory agreement with those provided by the reference sensor. The maximum deviation does not exceed 2K. However, the results of the oil temperature measurements of the wear-debris sensors and the ISO sensor exhibit a significant deviation from the actual oil temperature. This deviation increases with the oil temperature and reaches a maximum of 26K for a target temperature of 80°C, as illustrated in Figure 2.

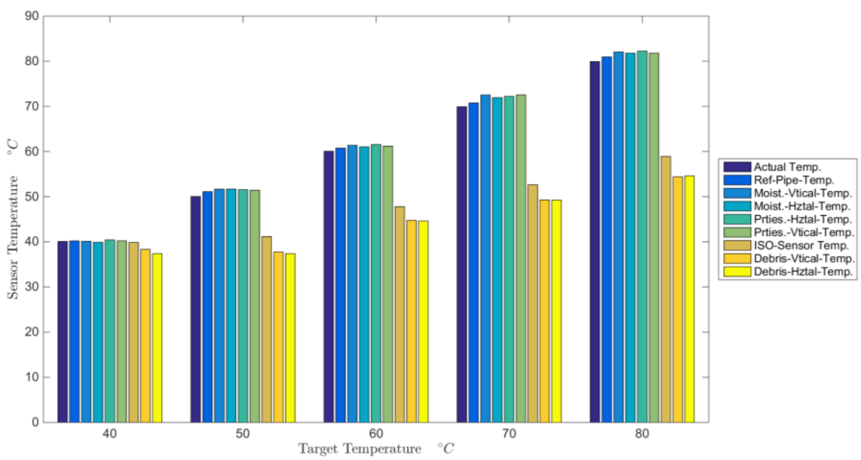

Figure 2: Oil sensor temperature measurements for different oil target temperatures with fresh PAO

This deviation can be attributed to the positioning of the temperature sensing element in the wear-debris sensor and the ISO sensor. For the moisture and oil-properties sensors, the temperature sensing element is in contact with the fluid. However, in the case of the ISO sensor and the wear-debris sensors, the temperature sensing elements are located within the sensor body, but they are not in contact with the fluid. As a consequence, the temperature measurements by these sensors are strongly influenced by the ambient temperature.

The same test, with the same temperature step profile was carried out two times with the PAO from the field to verify the repeatability of the results. This analysis shows that the temperature deviation of the oil-properties sensors and the moisture sensors is in good agreement with the previous measurements illustrated in Figure 2. However, the temperature deviation of the wear-debris sensors and the ISO sensors was still high for both the first and the second test. An important observation is that for the first test, the temperature in the surroundings of the sensor was lower than for the second test. These changes in the surrounding temperature of the sensors showed to have a strong influence in the temperature measurements, particularly for the ISO sensor. Higher temperature deviations were observed at lower surrounding temperature and vice versa. The repeated tests confirm the large inaccuracy in the temperature measurements of the ISO and wear-debris sensors due to the strong impact of the ambient temperature, as this large temperature deviation has been observed for both test profiles with fresh oil and with oil from the field. Therefore, the temperature measurements of the wear-debris sensors and the ISO sensors cannot be considered as valid indicators of the oil temperature.

Figure 3 illustrates the water saturation measurements as a function of the oil temperature for the step profile for the fresh PAO and its sample from the field. The measurements show, as physically expected, the decrease of the saturation level with increasing temperature [8].

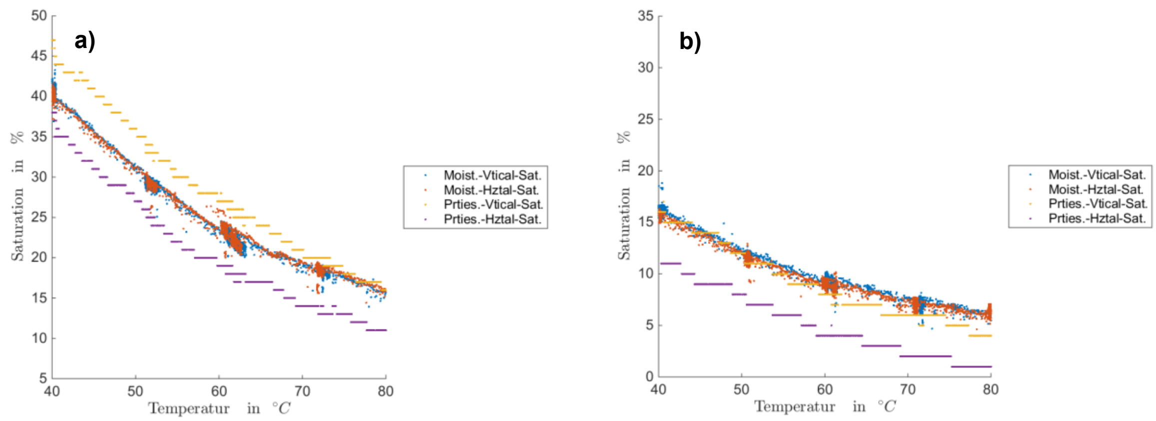

Figure 3: Water saturation level as a function of the oil temperature: a) Fresh PAO b) PAO from the field

The curves show that the saturation level measurements for the oil from the field are lower than for the fresh oil. An oil sample of both oils was extracted and sent to a laboratory to determine the absolute water content by Karl-Fischer-Titration [9]. According to the laboratory results, the fresh PAO and the sample extracted from the field have water contents of 37 ppm and 65 ppm, respectively. It is important to note that the saturation level also depends on the base stock of the oil and its additive package [8]. For the oil from the field, the additive content is reduced which can affect the initial saturation capacity of the oil. This indicates that after being used, the oil is able to retain more water showing a reduced saturation level, even if the oil has higher absolute water content.

The results also show that the horizontal oil-properties sensor has a deviation in the water saturation measurements of approx. 5% points of saturation. After swapping the positioning of the two oil-properties sensors, no changes in the measurements of water saturation were identified. This means that the deviation of the water saturation measurements of the horizontal oil-properties sensors is inherent to the individual sensor, and it is not related to its orientation or measurement principle. The test was repeated twice with oil from the field. The measurements of the saturation level of all sensors revealed a high precision. The maximum deviation of the measurement from the first test to second test did not exceed 0.5% points of saturation. A high precision indicates that the sensor measured almost the same values for the same profile more than one time. This indicates a good reproducibility of the water saturation measurements; however a comparison about the accuracy of the measurements is in this case not possible, as saturation reference values are required and a standardized method for the measurements of these reference values is not available.

Iron particles of sizes >100µm at 60°C were inserted in the test bench as illustrated in Figure 4. The online measurements for particles between 100 - 150µm are shown for the first two hours. The wear debris sensor used in this test provides a progressive summation of the particles that flow through the sensor, i.e. a constant value indicates that the sensor did not identify new particles in the passing fluid.

The results show that the sensor identifies and follows the injection of contaminants. However, the signals remain almost constant shortly after the injection of contaminants has been stopped. This indicates that the particles settle rapidly. Additional tests at different oil temperature levels analyzing particle sizes from 100µm up to 500µm show that both the oil temperature and the particle size have a significant effect on the settling velocity of the particles. This is an important finding: It implies that a damage generating wear debris can be identified by online measurements only during or shortly after its occurrence, as particles of this size have a high settling rate. In addition to this effect, the main oil circuit of a wind turbine gearbox should be equipped with a 10µm inline filter which continuously removes particles from the oil, as indicated in [10]. The positioning of the sensor also influences the particle counting. In the case shown in Figure 4, the wear debris sensor in the vertical pipe counted around 200 particles less than the horizontal sensor. This difference in the particle counting can be related to the deposition of particles which did not reach the sensor in the vertical pipe. An oil sample was extracted at the beginning of the test and 45 minutes after the 2nd injection, as illustrated in Figure 4. Interesting enough, the analysis of the oil sample carried out in the laboratory did not identify any iron particles and only a slight change in the impurities was found. These impurities usually designate additives or hard impurities such as dust or powder.

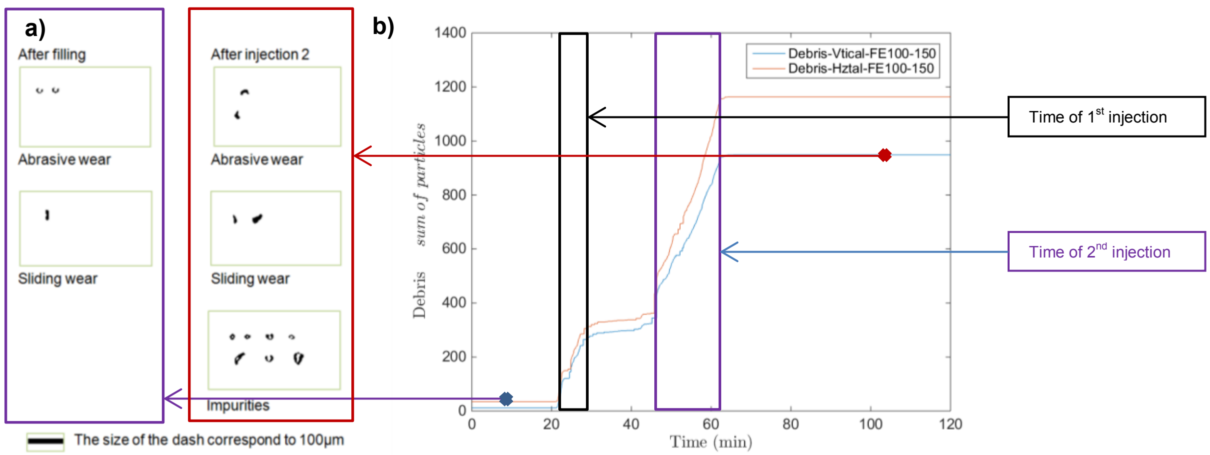

Figure 4: Test profile with insertion of Fe-particles of sizes >100µm: a) Particles from the oil samples extracted during the beginning of the test and after the 2nd injection. b) Online measurements of the wear debris sensors in the vertical and the horizontal position for Fe-particles between 100 – 150µm.

CONCLUSIONS

The results of this study show that the temperature measurements of some oil sensors are strongly influenced by the ambient temperature due to the positioning of their temperature sensing element within the sensor body. A useful oil-temperature measurement requires that the temperature sensing element is in contact with the oil.

According to the results of the saturation measurements, the horizontal oil-properties sensor showed a difference on the water content measurements around 5% points of saturation in comparison with the moisture sensors and the oil-properties sensor in the vertical pipe. From the tests, it was concluded that this difference in the measurements is not related to the orientation or the measurement principle of the sensor, rather to the individual sensor. A high precision in the output signal of the saturation measurements of all sensors was verified by repeating the test profiles obtaining a maximum deviation of 0.5% points of saturation. However to validate the accuracy of the saturation measurements, references values are still required. The water measurements by means of Karl-Fischer-Titration and the measurements of online saturation measurements indicate that the oil aging can have an influence in the capacity of the oil to get saturated.

The test with particle-contaminated oil shows that for particle counting with wear-debris sensors, the positioning of the sensor can have a strong influence on the particles circulating through the sensor due to high settling velocity of the particles with sizes of >100µm. This observation and the results of the offline oil analysis suggest the conclusion that wear debris in a wind turbine gearbox is detectable by means of particle counters only for a short period after debris generation and might not be detectable by means of offline oil analysis.

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KEYWORDS

Oil condition monitoring, gearboxes, wind turbines, oil sensors, oil sampling, wear debris, oil aging, water in oil