Measurement of Water in Oil for Active Bearing Performance Monitoring Using Optical Fiber Sensor System

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Abstract— **The utilization of an optical fiber sensor for the measurements of water in oil has been demonstrated. Absorption of light by water in oil in the near infra-red region (850 to 1650 nm) is measured with low noise level. Further, measurements of water contamination in oil with a minimum level of detection of around 0.002% were performed.**

Keywords-bearing; lubrication monitoring; oil; water; optical fiber.

I. INTRODUCTION

Measuring the quality of oil in real time, and suggesting corrective actions when needed constitutes real commercial market demand. In the past, several researches activities have been run regarding oil quality monitoring in bearings, to measure for example remaining lubricant life, the lubrication film thickness or investigating the capabilities of chemical or viscosity sensors [1-4]. Among all these parameters, one of the priorities of the lubrication experts is to measure the quantity of water in the oil and especially the percentage of water saturation of the oil. Indeed, water incursion into the oil can have a major impact on the lifespan of the bearings. In general, depending of the type of the lubricant, the water level accepted can be in a range of 200 ppm to 5000 ppm.

This article is focused on the development of a sensor system based on one immersible open path optical fiber sensor for measuring the concentration of water in oil. In Section 2, the sensor concept is introduced and the measurements results are presented. In Section 3, conclusions are summarized.

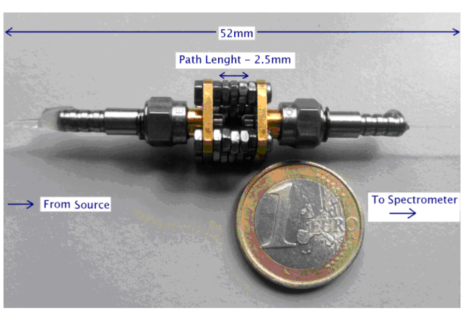

Figure1. Optical sensor

II. CONFIGURATION OF THE SENSOR

An open path configuration was chosen as the sensing element for delivering a high level of sensitivity. Optical fiber cable, capable of operating effectively within the range 850 nm – 1650 nm, was sourced and tested to ensure a significant level of transmission in this wavelength range. An standard fiber connector (SMA) based miniature coupling cell, fabricated out of brass and stainless steel, was configured to be used as the sensing element. A photograph of the sensing element is shown in Figure 1.

During the testing stages, the sensing element (Figure 1) was simply immersed in the oil sampling medium. Light from the Tungsten light source propagates through a 400 mm length of optical fiber before traversing across an open path space where it interacts with the sensing medium. The light is then coupled back into a second length (400 mm also) of optical fiber before being recorded by a spectrometer located at the receiving end.

The use of dedicated optical fiber and a small open path length resulted in a significant amount of light intensity being detected by the spectrometer. The choice of the length of open gap in turn resulted in a optimum accuracy of the absorption measurement through the S/N ratio.

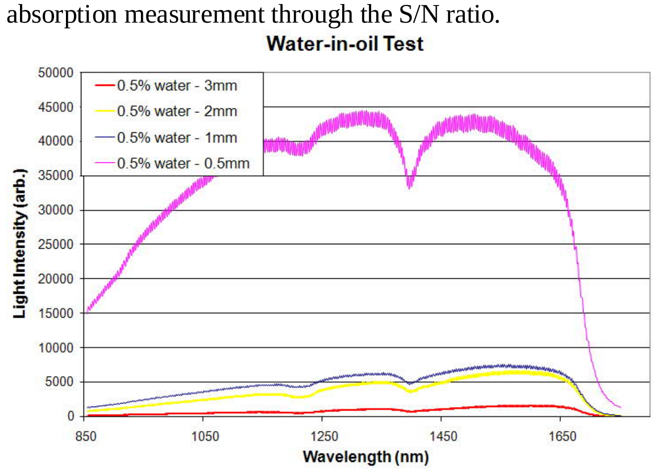

Figure 2. Light transmissions through 0.5% water in oil mixture depending of open path length 0.5, 1, 2, 3 mm

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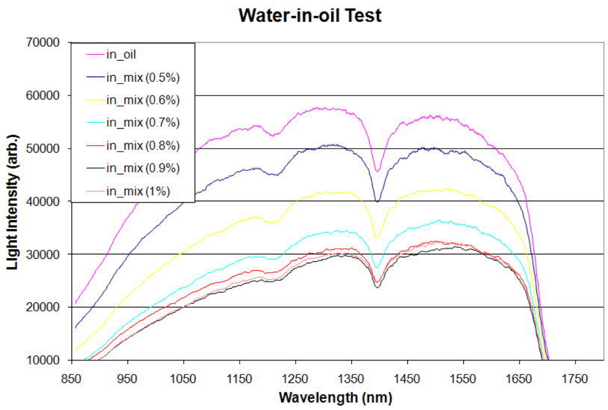

Figure 3. Light transmissions through different water in oil mixture samples

A. Path Length

Preliminary tests were taken to record the effects of the sensing system with regards to path length changes within the sensing element. For this a number of sensing elements were constructed (lengths 3 mm, 2 mm, 1 mm and 0.5 mm).

Significant sensitivity for water incursion was detected for each of the sensing element including the smallest one of 0.5 mm (see Figure 2). Therefore, taking the signal-to-noise ratio into consideration, the 0.5 mm sensing element was chosen for use within the sensor for the subsequent tests.

B. Measurements

1) Sensitivity Tests

Sensitivity testing comprised seven samples of testing liquids used during the testing stages; these were 0% and 0.5% through to 1% water content in oil (Cirkan C100). The samples were mixed using an ultrasonic bath. The resulting intensity spectra can be seen in Figure 3.

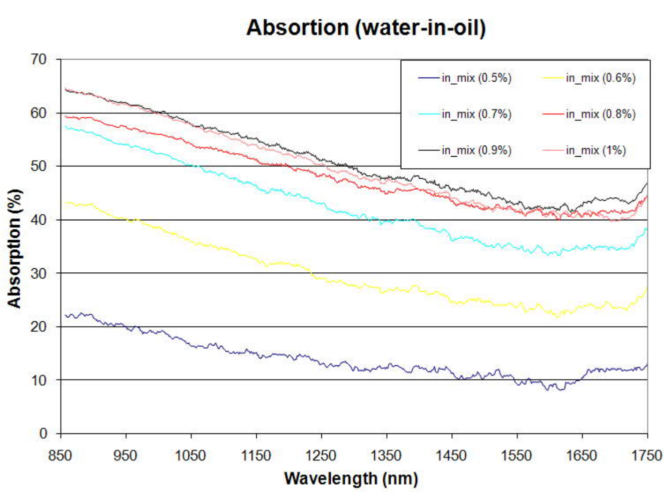

Figure 4. Light absorption for different water in oil mixture samples

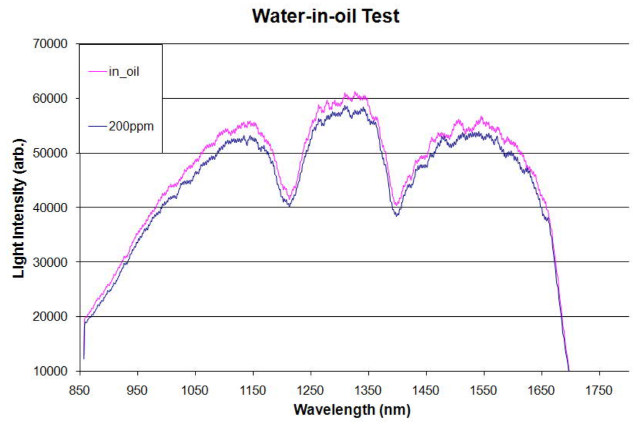

Figure 5. Light transmission spectrums showing a difference of 200ppm water in oil concentrations of two oil samples

The differences in the absorption percentages of the light recorded for mixed water in oil samples (0.5% to 1%) referenced to the light intensity recorded during the pure oil test was calculated and can be seen in Figure 4.

2) Lower-Detection-Limit

Recently, the lower detection limit of the sensor has become a major factor, with targets of 50 ppm water-in-oil. To achieve this accuracy in the mixing stage necessary mixing equipment such as a micropipette (capable of 2.5 um deliveries) were used.

Due to constrains in access to the experimental testing rig only one sampling experiment has been completed thus far (at least two of every experiment has been completed up to this stage – this was deemed necessary in order to correlate results in an accurate manner). In order to enhance sensitivity an increased path length of 2 mm was chosen.

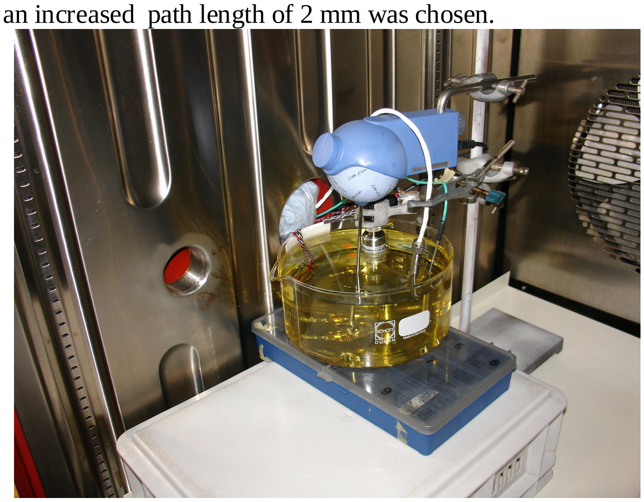

Figure 6. The Hydac, Pal and optical SKF sensors measuring in parallel in a well controlled humidity chamber

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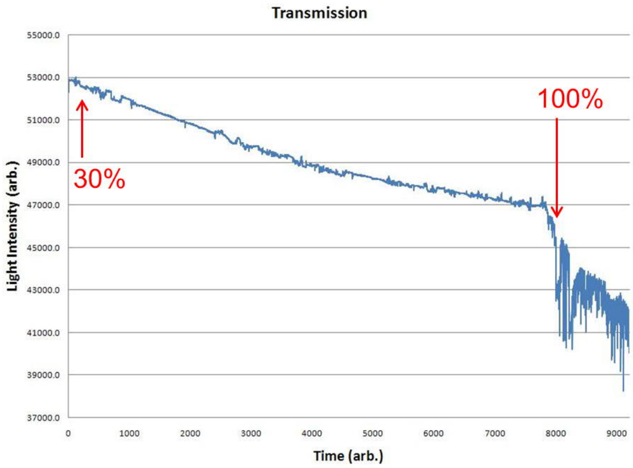

Figure 7. Light transmission variation (wavelenght of 1108 nm) for change of mineral oil saturation between 30-100%

The concentration chosen for this experiment test was 200 ppm and as can be seen from the result in Figure 5, a significant amount of absorption was recorded.

3) In-Situ Experiments

The sensing element was placed into a bath of mineral oil which in turn was placed into an environmental chamber where the humidity and temperature are very well controlled. The concentrations of the water within the sample were thus varied by accurately changing the temperature and humidity within the chamber.

The measurements were performed in parallel with one Hydac aqua sensor (type AS1008-C-000) and one Pall (type WS05S) water in oil commercially sensors for calibration purpose (see Figure 6).

The full spectrum was recorded over a number of hours during which the concentration of the water was gradually increased. The concentrations were increased steadily over a number of hours until saturation level in oil was reached (more precisely about 100% saturated).

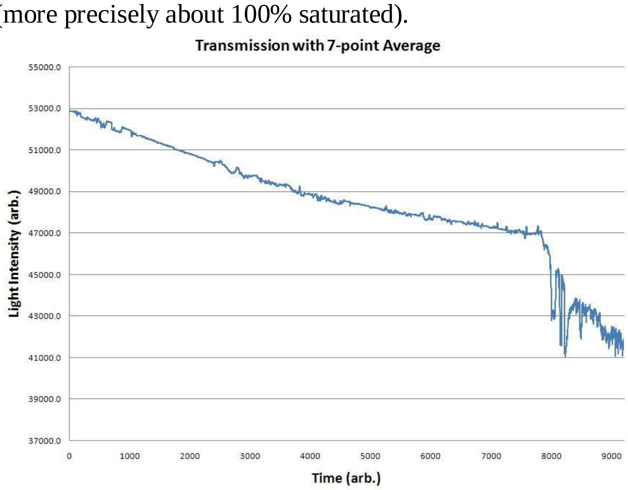

Figure 8. Averaged measurements for light transmission variation (wavelenght of 1108 nm) for change of mineral oil saturation between 30 - 100%

The measured optical transmission for the full experimental test recorded at a wavelength of 1108 nm is shown in Figure 7.

The results show a strong and stable response to the ever increasing levels of water content. However, when the sample reaches a level above saturation, the sensor records a significant increase in measured noise levels. The sampling frequency of the measurement was 2 Hz, and the measured noise level can be significantly reduced using digital filtering such as a moving point average (see Figure 8).

Although, this shows a reduction in the level of noise, it is expected that additional averaging and filtering will further reduce this. In fact for the response shown above and taking a signal-to-noise level of 1 into account, the lower detection limit of the sensor can be estimated to be below 20 ppm. The final graph (Figure 8) simply has shown the percentage absorption taken from the in-situ experimental results. These percentages also correlate to experimental results previously taken in the lab (specifically during the sensitivity testing stage).

An interesting conclusion is that after reaching 100% oil saturation, the measurements of the optical sensor become apparently instable due to the free water oil content. An important advantage of this is the possibility to autocalibrate the sensor for different types of oils. The 100% saturation limit can be detected very precisely.

One more observation was done for free water region. Based on averaging the measured signal the water content can be estimated. All these observations make the sensor unique.

These experimental results have shown that the sensor portrays a significant level of resolution of 20 ppm, a wide range of detection (20 ppm – 10000 ppm. In a future development, microspectroanalyzers or cheap LED's should be integrated in the readout measurement system for scaling down the price of the sensor unit.

III. CONCLUSIONS

The results of the experimental investigation of water content in oil using a novel optical fiber sensor system have resulted in the following successful outcomes:

- The saturation of water in oil (Circan 100cc) was measured
- Measurements were done in a range of 30-100% Relative Humidity (RH)
- The accuracy of measuring the water concentration is around 20 ppm (0.002%)
- The sensor shows good capabilities to measure also emulsified water and free water
- The sensor can be easily auto calibrated for 100% oil saturation

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