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Impact of Gearbox Oil Contamination on the Performance of the Wind Turbine Drivetrain

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Abstract –

Wind turbine gearbox is a key component in any wind energy conversion system and online monitoring of the gearbox is essential to maintain system reliability. This paper investigates the impact of gearbox lubrication oil contamination on the performance of wind turbine drivetrain. In this context, vibration signal of the gearbox is measured and analyzed under various contamination levels of the gearbox oil. A thermal camera is used to identify the hot spot location within the gearbox during the investigated case studies. Results show that quality of gearbox oil has a significant impact on the overall performance of the wind energy conversion system.

Index terms – Condition monitoring, Drivetrain, Gearbox, Oil contamination, vibration analysis, Wind energy.

I. INTRODUCTION

Condition based maintenance (CBM) has been an effective technique used to extend the life cycle of wind turbine [1]. Due to the high thermal and mechanical stresses on the drivetrain of wind turbine, gearbox lubrication oil is subject to degradation including corrosion, water and particle contamination that affect the performance of the gearbox and hence the overall performance of the wind energy conversion system (WECS) [2]. Vibration analysis has been widely used to monitor the condition of rotating machines to identify incipient faults and facilitate root cause failure analysis in order to enhance the life cycle of rotating machinery [3] [1]. Several papers in the literatures proved that vibration analysis is one of the most suitable predictive maintenance techniques for industrial machinery [4-8]. Wang and McFadden [9] investigated the use of vibration analysis as an early detection technique for gear failure. Power spectral analysis using fast Fourier Transform (FFT) is used in [10-12] to extract the features of the measured vibration signals. Tan *et al* [13], investigated the capabilities of the acoustic emission, vibration and spectrometric of lubrication oil for spur gears and how it affects the gearbox aging life cycle. Impulse vibration signals and acoustic emission technique have been successfully used to monitor the condition of the gearbox in [14], [15]. Gearbox lubrication oil is facilitated to detect wear of rotating components [1, 2, 4], [16-18]. Fischer *et al*, state that lack of proper condition monitoring technique may lead to major failure to the whole system, thus, identifies and corrective actions to the main failure cause as well as a proper maintenance strategy selection will improve reliability of the wind [19]. Oil degradation leads to high thermal stress within the gearbox of wind turbine that increases bearing temperature and accelerates oil aging [20]. Oil quality can be assessed through the measurements of some parameters such as level of oxidation, acidity, viscosity, water content, temperature and dissolved particles [21, 22].

II- SET UP CONFIGURATION

Fig. 1 shows the test rig used to emulate real operation of a wind turbine. The test rig consists of an induction motor that represents wind turbine blades connected to a synchronous generator through tow shafts coupled through a gearbox. Four accelerometers with low (0.1 Hz) and high (1 kHz) frequency and sensitivity of ±10% are installed on the drive train at different locations to measure the drivetrain vibration signals. As the location of sensors has a significant impact on the measured signal, a great attention should be given to the location of sensors. The two stage helical gearbox (type NHL25) used in this experiment has a teeth ratio of 1: 4.34. Torque signal is measured using a transducer fitted on the low speed shaft of the gearbox. Table 1 shows the characteristics of the mineral lubricants used within the gearbox along with ISOVG (International Standards Organization Viscosity Grade).

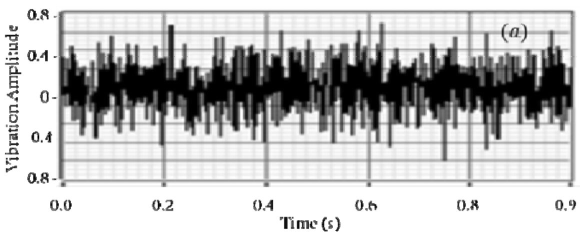
Table 1 Oil types and specifications

Mineral Oil type	Viscosity At 40°C	Density, kg/L
ISOVG 220	224	at20°C 0.861
ATF MHP	37	at15°C 0.849

Fig. 1 Test Rig setup

III- Results and Discussion

Fig. 2 shows the measured vibration signal under new and contaminated lubrication oil. Oil is contaminated through dissolving 100grms of fine iron powder in the oil. Figure 3 shows the vibration signal of the drivetrain when a current of 8 A is injected to phase A of the generator stator winding to emulate real loading condition. As can be seen in Fig. 3, the magnitude of the vibration signal is increased when compared with the no-loading condition shown in Fig. 2. This is attributed to the high injected current to the generator stator windings which creates an opposite torque causing high mechanical stress on the generator shaft then consequently on the gearbox. Fig. 3(b) shows the power spectrum of the measured vibration signal with peak hold technique to easily identify the maximum peaks. Fig. 3 reveals that peaks of the measured vibration signal take place at 13.3Hz, 53.3Hz and 130Hz. These frequencies represent zero, first and second frequency modes. Fig. 3(c) shows the rotor spectral map from which it can be observed that the speed of the rotor (800 rpm) is corresponding to order 1; the first frequency oscillating mode (53.3 Hz). Fig. 4 shows that the power spectrum is decreased when compared with that of Fig.3. This is attributed to the contaminated oil that leads to a change in oil viscosity and leads to wear and tear within the gearbox. The time data collection was not enough to observe the real effect of gearbox degradation, minimum of six months is required to have a solid data to compare. In Fig. 4 (c) the spectral map of the new oil before contamination process and under load conditions shows the differences in order spectrum between this stage and Fig. 3 (c).
There is no considerable difference between the new oil (type ATF MHP) under normal operating condition and the original oil type (VG 220) in terms of torque variations. Fig. 6 shows different experiments conducted on the test rig setup, high speed 700 rpm healthy condition (a), and low speed 200 r/min contaminated lubricant conditions (b) and faulty conditions 200 r/min (c). Comparing the measured three torque signals shows that a significant increase in the torque between (b) and (c) due to gear tooth surface wear as a result of a contaminated lubricant. Fig. 6 (a) illustrates the effect on wind speed and the side effect on the torque pattern which involves a mechanical stress and increase fatigue life on the drive train of the wind turbine.



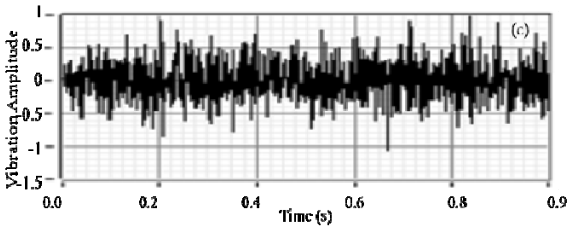
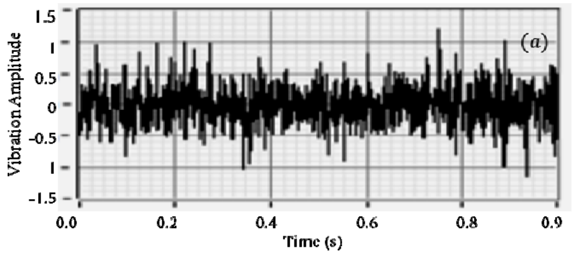
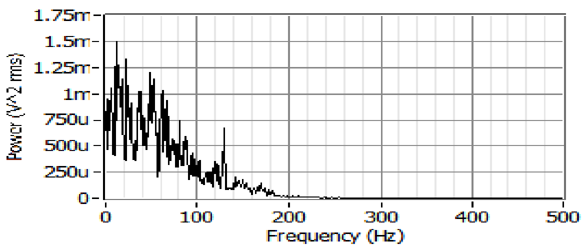
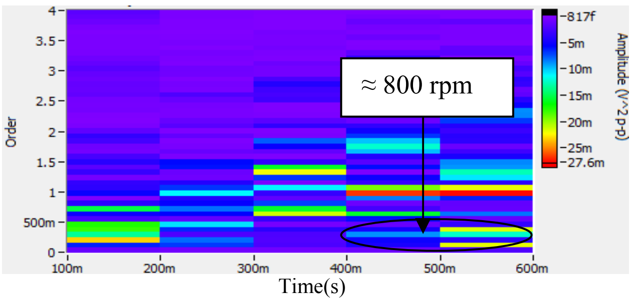


Fig. (2) (a) New oil ATF MHP, (b) New oil ATF MHP after contamination, all under normal operating conditions.



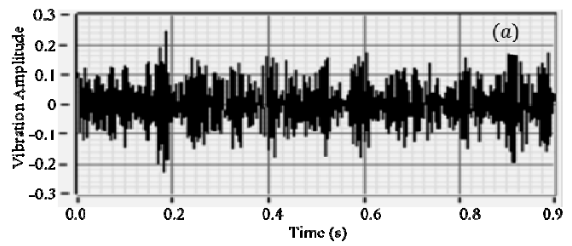


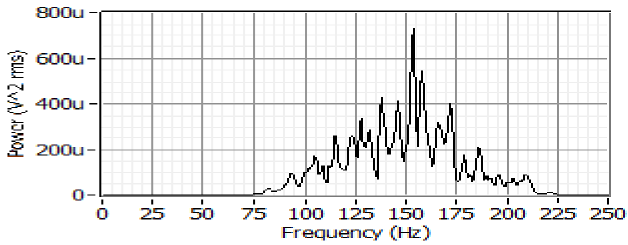
(b)



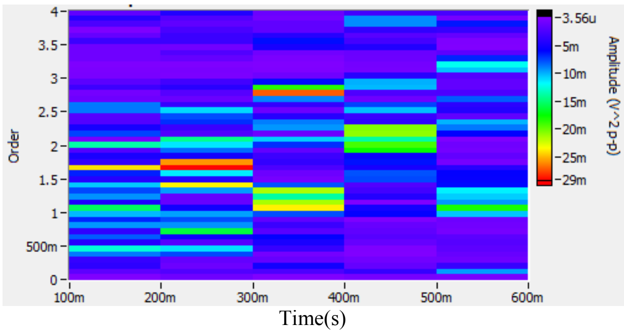
(c)

Fig. (3) (a) New oil after contamination and under load variations, (b) Power spectrum of the signal (a), (c) Spectral map





(b)



(c)

Fig. (4) (a) New oil before contamination and under load variations, (b) Power spectrum of the signal (a), (c) Spectral map

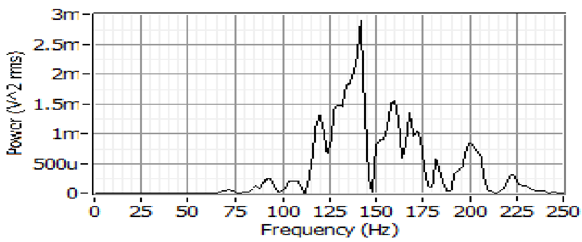
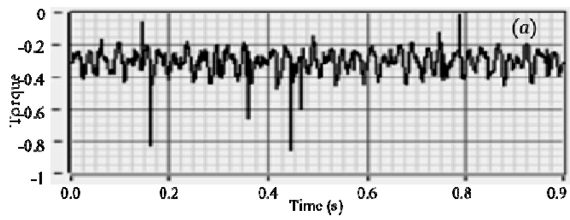
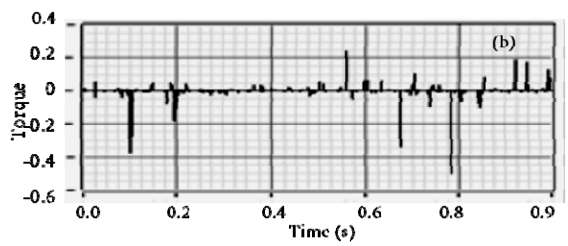


Fig. (5) Power spectrum of contaminated ATF MHP oil under load variations





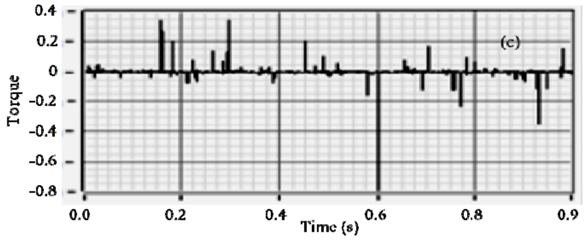


Fig. (6) (a) Torque signal with contaminated oil at high speed under load variations, (b) Torque signal with contaminated oil at low speed and normal operating conditions , (c) Torque signal with contaminated oil at low speed and under load variations

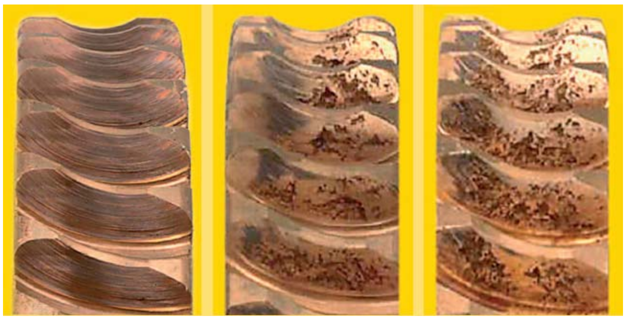
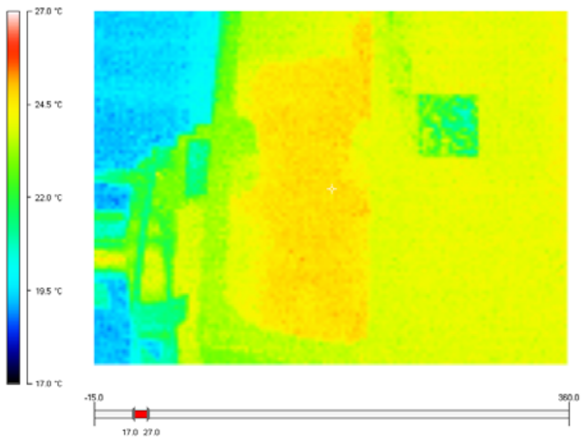
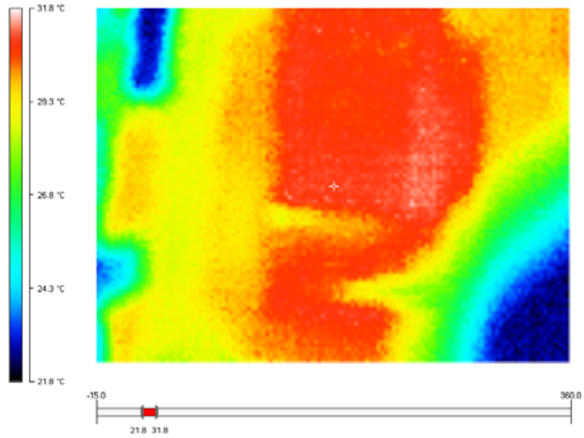


Fig. (7). Aging sequence of the gearbox teeth under incorrect lubricant [23].

Fig. 7 demonstrates the aging life cycle of the wind turbine gearbox teeth from new to end of life. Aging acceleration in the gear box takes place due to many factors such as oil viscosity, moisture content, oxidation and temperature that will cause scuffing and tooth thickness damage. Top quality oil will improve gearbox defence, extended its life, increase efficiency and improve seal capability as well as overall performance of the wind turbine.



(a) Gearbox running before lubricant contamination



(b) Gearbox running after lubricant contamination

Fig. (8). Thermal images of the gearbox under different lubricant conditions

A thermal imager (Fluke Ti20) is used to record the thermal images of the lubricant before and after contamination at 27°C as shown in Fig. 8. Before oil contamination, there is no sign of overheating within the gearbox as shown in Fig. 8(a). On the other hand Fig. 8(b) shows an overheating spot within the gearbox due to oil contamination. This may lead to the increase of mechanical losses by increasing gear friction as well as extreme rubbing wear may occur.

IV. CONCLUSIONS

In this paper, experimental measurements have been conducted on a test rig that simulating wind turbine operation to study the impact of oil contamination on the overall performance of the drivetrain. Results show that the vibration and torque oscillations depend on oil lubricant condition. Contaminated oil leads to overheating within the gearbox and generates peaks on the vibration signature at the zero, first and second frequency modes. Oil lubricant with high viscosity grade and contamination free will enhance the overall performance of the wind turbine and achieve better condition monitoring by detecting faults at early stages. Furthermore, smoothing the drivetrain torque signals will result in less mechanical stress and therefore in decreasing the drivetrain component fatigue life.

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