Condition Based Monitoring of Gearbox Transmission Using Wear Particle Analysis Technique

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Abstract

Nowadays machinery condition monitoring is a comprehensive technique through which information about predicted failures could be extracted. This leads to improve reliability program such as time-based preventive maintenance. Without such improvement, this type of maintenance would lead to un-expected down time and thus more hidden costs of production. Machinery condition monitoring is necessary for any plant that strives to achieve its production goals. There are various condition monitoring techniques such as vibration analysis, thermographic analysis, ultrasonic detection, oil analysis and wear particle analysis. Wear particle analysis is considered a vital tool for condition monitoring in many lubricated machines. The main objective of this work is to apply condition-based maintenance using wear particle analysis for an industrial gearbox. The targeted gearbox is considered a crucial equipment attached to a carpet weaving machine, which is supposed to have the minimum possible sudden shutdown. The gearbox is Elasto-hydrodynamically lubricated and was conducted for monitoring through six months of sampling interval. Periodic samples of lubricant were taken and analyzed through spectrometer and laser net fines (LNF) equipment where elemental and Ferrographical analyses are applied respectively. Recommendations were addressed for better performance of the gearbox.

Keywords
Wear particle analysis, condition-based monitoring (CBM), Laser net fines (LNF), reliability and maintenance.

1. Introduction
1.1 Machinery wear

In any lubricated machine, wear is considered an inevitable event. Thus, it is quite important to control this wear process in-order to extend the operational life of the machine and production process sequentially (M.C. Isa, 2013). Mainly, four types of wear could be found in any lubricated machine; adhesive wear (sliding), abrasive wear (cutting), corrosion wear (chemical) and fatigue wear (Fitch, 2013). The most two dominant wear modes that could be found are adhesive and abrasive wear modes (Raadnui, 2005). Adhesive wear is found where two moving surfaces are pressed under sliding conditions; as in gears, bearing cams and followers (Memon, 2004). The interfacing asperities between the two surfaces tend to make an adhesion action with each other, as the surface atoms of both materials for the two surfaces are inherited to attractive forces (Rigney, 1980). Through continuous sliding motion, asperities are broken and introduced either along one of the contacting surfaces or introduced into lubrication as wear debris (Ashwani Kumar, 2019). These adhesive wear debris will affect the contact surfaces by making scratches and ploughing in both sliding parts. Generally, adhesive wear could be due to many reasons, insufficient supply of lubrication, inappropriate viscosity (high operating temperature or the used oil is not appropriate), misalignment between components as in motors and gear systems, slow operating speeds and higher loads applied to components; or combination of those reasons. This eventually leads to high metal to metal contact instead of carrying the load by the lubricant, (Garvey, 2012). The second dominant wear mode is Abrasive wear, which is classified into two categories; two-body abrasion (2BA) and three-body abrasion (3BA), (4) (L.Norton, 2006). In 2BA the, the abrasion occurs due to the deep contact of asperities between the two mating surfaces as one of them is rougher than the other. On the other hand, 3BA occurs due to the existence of hard particles (dust contaminants, sand particles or wear debris generated from other wear modes) that inherited in between the two-mating surface. Generally, abrasive wear could be reduced as much as possible by enhancing the filtration process and appropriate selection of the lubricant (Scott, 2008), (Mechefske, 2005).

1.2 Machinery condition monitoring using wear particle analysis

There is vast array for machinery condition monitoring techniques such as oil analysis, Vibration analysis, Acoustic emission, and Thermal analysis (S. Akl, 2015). For oil analysis, there are two major approaches, used oil analysis and wear particle analysis. In used oil analysis, the capability of the lubricant to carry loads and work efficiently is analyzed through many tests, such as viscosity index(VI) and Total acid number(TAN) (Idhammar, 2000).While for wear particle analysis, the history of wear particles concentrations and morphological data are mentored to predict any failure event of internal lubricated components. Monitoring process of these components is carried out through a precise analysis of periodic samples for lubricant using two major analysis tests, Spectrometric and Ferrography (Ashwani Kumar, 2019). For Spectrometric analysis, elemental investigation is implemented to determine the concertation of worn elements such as Copper (Cu), Iron (Fe), Silicon (Si) and Nickel (Ni) in particle per million(ppm) units. However, the accuracy of the spectrometer is limited to identify wear particle size up to 5 microns, which justify a primary wear mode, and the accuracy is reduced for particle size in between 5 and 10 microns, which justify an advanced stage of wear modes (Jonson, 2009). For Ferrography analysis, the morphology and surface topography of wear particles are investigated to classify the wear modes inherited in the lubricated machine. LazerNet Fines equipment is used to generate this sort of analysis, it can detect wear mode with wear particles in size range from 20 to 100 microns (David Filicky, 2002)

2. Experimental Approach

Wear particle analysis was implemented to monitor the condition of a critical carpet manufacturing machine. This machine has a transmission gear box that is used to handle a high-speed reciprocating knife arm which picks carpet fibers in forward and backward motion to weave the final shape of the carpet. The gearbox is Elasto-hydrodynamically lubricated with Total CARTER EP 220. Six oil samples were taken periodically from the gearbox over a period of six months. Spectrometric and LaserNet Fines analyses were applied to all samples.

3. Results and Discussion

3.1 Elementary analysis

With a view to get more powerful spectrometer analysis, Spectrometric results in particle per million (ppm) were modified using statistical approach (Troyer, 2005). By using this statistical analysis, alarm limits (critical and cautionary limits) would be established by calculating the rate of change (ROC) for most dominant wear elements. The ROC is function of operating hours of the gear box, wear rate and lubricant volume. Equation 1 shows the formula of the ROC (Mayer, 2005).

$$Rate\ of\ change\ (RoC) = \dot{X}_m \left(\frac{ppm}{100*hour}\right) = \frac{x_0 - x_{-1}}{t_0 - t_{-1}} * \left(1 + \frac{v}{V}\right)$$

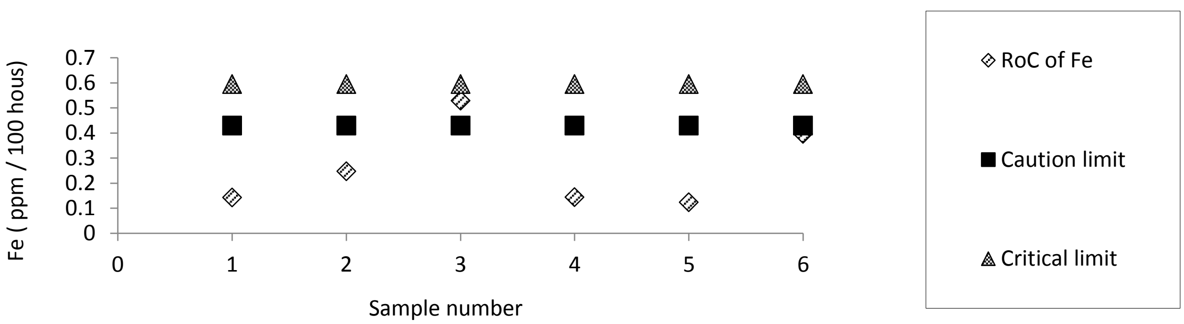
(1)

Where $\boldsymbol{x_0}$ and $\boldsymbol{x_{-1}}$ are readings of present and preceding for concentration of an element in ppm, $\boldsymbol{t_o}$ and $\boldsymbol{t_{-1}}$ are the present and preceding working time of the gear box in hours, $\boldsymbol{v}$ is the amount of makeup lubricant added to the sump from the last preceding sampling, and V is the total sump volume of the gear box. Then mean and standard deviation for each wear element could be calculated using equations 2 and 3.

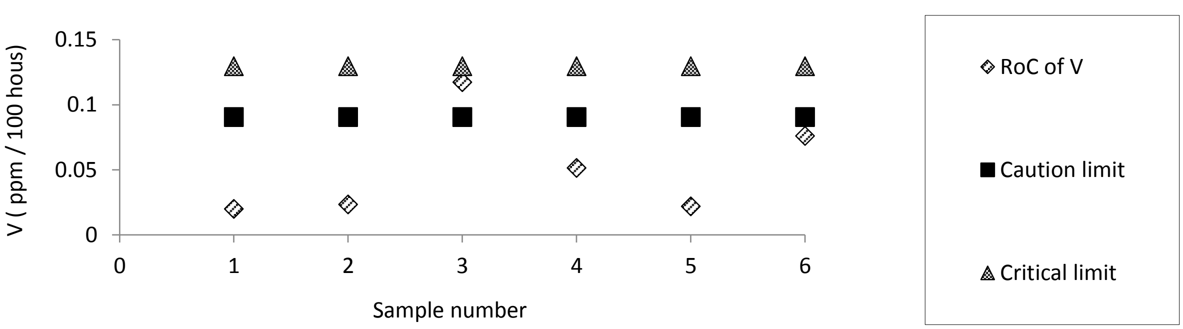
$$Average(mean) = \frac{\sum x_i}{n} = \frac{(x_1+x_2+\cdots+x_3)}{n} = \bar{x} \quad (2)$$

$$Standard\ deviation = \sqrt{\frac{\sum(x_i-\bar{x})^2}{n-1}} = S \quad (3)$$

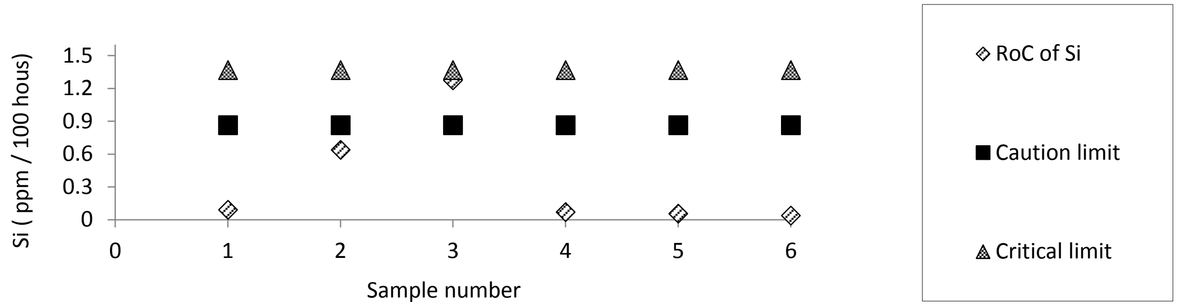
Where $\boldsymbol{x_i}$ is the ROC for a specific wear element and n is the total number of periodical samples. Critical limit is considered as a potential signal for a predicted failure, and once the ROC is approaching this critical limit, a necessary and quick action is required immediately to prevent a catastrophic failure as could as possible. Critical limit is determined by summing the mean and twice the standard deviation of the ROC for each wear element ($\bar{x}$+ 2S) (Mayer, 2005) .Whereas, cautionary limit is an indication for a primary failure incident that would need Inevitable checkup action, e.g. checking the temperature and sump level of lubricant. Cautionary limit is determined by summing the mean and the standard deviation of the ROC for each wear element. Figure 1 clarifies the ROC for the most dominant wear element in the gear box (Fe, V, Si and Mn), which would come from many steel alloys that inherited to many internal components within the gearbox as shafts, pin and gears. It is noticeable here, that the ROC had exceeded the cautionary limit and approached the critical limit through sample number three for most of elements. The condition of this test was investigated. It was found that there was a problem with oil sampling for that test, as it wasn't done by the right way. So it gave a misleading result.



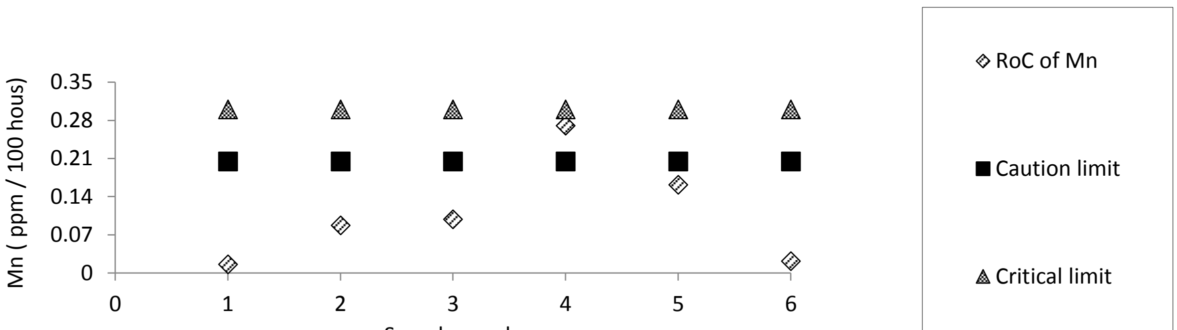
(a)



(b)



(c)



(d)

Figure 1. Rate of change steel alloy components (a) Iron, (b) Vandium, (c) Silicon, (d) Manganese

3.2 Ferrography analysis

For more accuracy and quick ferrography results, Laser net fines Q200 equipment had used in this type of analysis (David Filicky, 2002). Through ferrography analysis, many wear modes could be detected within the lubricant. This includes, sliding(adhesive), cutting(abrasive) and fatigue wear.LNF results are showed in Figure 2. The number of wear particles in sample number three was abnormal compared with other samples. Results were confirmed with the spectrometric analysis which showed incremental change in ROC during this period of sampling.

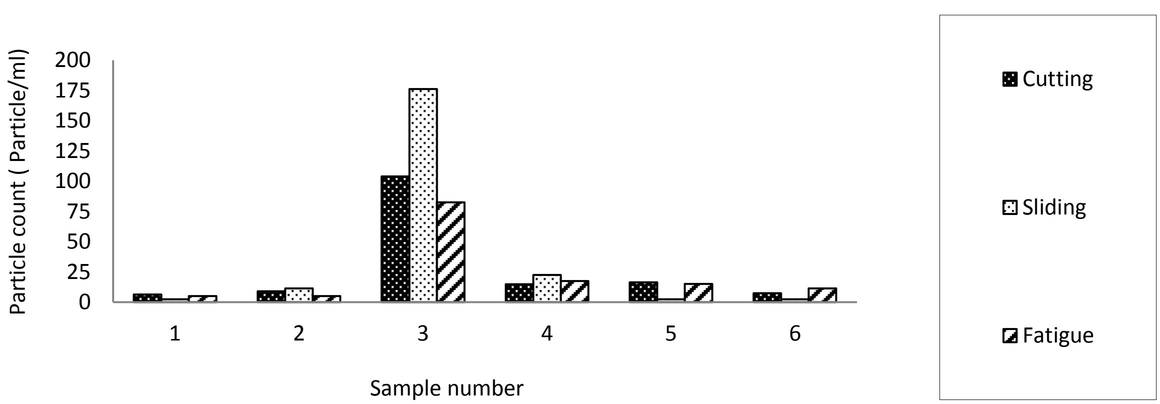


Figure 2, Distribution of wear modes in the gearbox

4. Conclusion and suggestion for future development:

The approach of wear particle analysis is considered as a powerful tool of diagnosis, prognosis and life predictions of components and subsystems at any major production lines, where the cost of sudden shutdown had to be minimized. This approach would enhance a reliability program if it is accompanied with other condition-based monitoring (CBM) techniques, such as vibration analysis. Through this study, a subsystem of a critical gearbox was monitored using wear particle analysis technique. Elemental analysis of the worn particles was implemented using spectrometer, through which a trend of wear process inside the gearbox was established to evaluate the health condition of internal components within the gearbox. Moreover the trend of wear process was implemented using statistical analysis to establish wear limits and rate of change (ROC) for most dominant worn element in ppm/100hr. Ferrography analysis was also implemented to investigate the concentration of each wear mode that had been generated within the lubricating system in particle/ml. Ferrography analysis was implemented using laser Netfines (LNF) equipment. Results of both elemental and ferrography analyses had justified each other. All the results confirm normal function for the tested gear box , except the third result as explained above.It was recommended for this company to apply the wear particle analysis to their critical machines to enhance their maintenance program. Also, this will affect the plant inventory management program to reduce the worn spare parts and hence the operational costs.

Biographies

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