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Prognostic Approach for Ferrographic Analysis of Gear Box

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Abstract : *Wear particle characterization is important feature to get the overview of machine condition monitoring as most of the failure occurs due to wear debris saturation. Ferrography is one of the important techniques used to separate wear particles from lubricating oil and examining them under bi-chromatic microscope. The objective of this paper is to calculate the wear severity index of lubricating oil samples using direct reading ferrography and to study the wear trend using analytical ferrography. This date can be used to diagnose the fault and decide oil maintenance policy*

Keyword: *Ferrography, Ferrograph image, Wear, Wear severity index, Condition monitoring,*

I. Introduction

Examination of wear particle is one of the most important factors for machine condition monitoring. Wear particle analysis provides information on machine condition due to different particle morphology (size, shape, color, surface texture, boundary representation) [1]. The obtained information from wear particle analysis support in the early detection of abnormal wear which will indicate increasing rate in failure, and detection of mode and mechanism of wear and its severity [2]. It can also help to give the insight about the machine condition and decide the maintenance period [3][4].Condition monitoring is used for identification of significant change which indicates the developing fault, which is used to prevent consequential damages of machine component [5]. There are different techniques used for condition monitoring like vibration monitoring, acoustic monitoring, ultrasound technique, signal processing. Most commonly used condition monitoring technique is oil and wear debris analysis. There are different methods used for wear particle analysis like atomic absorption spectroscopy, atomic emission spectroscopy, ferrography, wear particle boundary description using image processing and fractal techniques. Ferrography is one of the important techniques used for wear particle analysis which is divided into two groups direct reading ferrography and analytical ferrography [6]. Ferrography was invented by D. Scott, of the National Engineering Lab, U.K, in 1970 [7]. Direct reading ferrography is a quantitative approach used to determine large and small sized particles present in the oil sample along with wear severity index and wear particle concentration. Analytical ferrography is a qualitative approach used to study wear trend, shape and size of wear particles using dual slide ferrogram maker and bi-chromatic microscope. Ferrographic analysis is significantly used for identification of images, to get the wear particle morphology and their classification to assess state of wear, wear rate and mechanism [8]. Few Literatures studies are mentioned below

Manoj Kumar [1] discussed the difficulties to identify wear particle and to monitor the health of equipment. Factors which are determined during wear particle analysis are quantity of wear particle, morphology, color & chemical form of wear particle. The paper explains types of wear and wear particle mechanism. Wear particles are categorized as rubbing, cutting, spherical, laminar, chunk, severe sliding.S. Ghosh, et. al. [2] worked for alternative approach to characterize wear particle with the help of image vision system for gear box condition monitoring. Conventional process for machine condition monitoring through identification of wear particle requires expert advice and is time consuming. Ferrographic technique was applied on lubricant, to find the type of wear by applying image processing. Wear particles were analyzed with boundary morphology and surface topography by calculating area and FD (fractal Dimension) parameter.Ivan Plascak, et. al [5] reviewed the significance of technologies used for early prediction of machine wear through analysis of lubricating oil using ferrography. Maintenance of tribological system influences their reliability and decreases the occurrence of failures. Advantages of condition based maintenance are extended interval of preventive maintenance, reduced possibility to replace a wrong machine, reduced number of working hours needed to perform maintenance, decreased demand for spare parts.

D. Scott, et. al [6] explained the procedure to perform ferrography for machine condition monitoring in order to replace expensive periodic dismantling of machinery. It can take follow up of the rapid increase in quantity of wear particles, which help to indicate the initiation of a more severe wear process. Author has differentiated the appearance of wear particle like rubbing wear which looks like platelets and they indicate normal permissible wear, cutting or abrasive wear particle take the form of miniature spirals, loops and bent wires similar to swarf, sudden increase in concentration of such particles in successive lubricant samples indicate imminent machine failure.N Govindarajan, et. al [7] performed experiment on powder metallurgy steel for rolling- sliding contact fatigue. Lubrication oil was collected for regular interval to predict wear rate of powder metallurgy steel using ferrography. Ferrogram slide was prepared by using ferrogram maker. Ferrous particles were deposited on to slide according to size of the wear particle. Surface peeling and pitting type of failure were observed in sintered and hardened rollers. Numbers of fatigue chunks were lower in wrought steel compared to sintered steels. The study depicts, qualitative and quantitative ferrographic analysis of wear particles in lubricant collected from gear box. The wear test ran for four time periods successively in 200, 400, 600, 800 hours. Four used lubricated oil samples were collected from the gearbox for qualitative and quantitative analysis. Characteristics of wear particles were experimental over Olympus BX52, bi-chromatic microscope. Quantitative data revealed that wear severity index goes on increasing with respect to time.

II. Experimental Procedure

1.1 Test Instrument:

The experimentation was carried out on new gear pair and it was run till 800hrs, oil samples were collected after 200hrs of running. The lubricant is a powerful source of information on machine condition since, if the oil deteriorates, then so too does the machine condition [9]. Quantitative analysis of oil sample was carried out using direct reading ferrography (DR-5) as shown in figure 1. Qualitative ferrographic analysis of lubricant was carried out using dual slide ferrogram maker and Olympus BX52, bi-chromatic microscope as shown in figure 2. In Analytical ferrography, wear particles are separated from the lubricated oil samples by magnetic field. Lubricated oil sample is diluted using fixture oil for proper precipitation and adhesion of wear particles on glass slide [10]. This sample flows through a particularly designed glass slide known as ferrogram slide with dimensions 60x25mm. Due to magnetic field larger particles get settled at the entrance point, after the particles get deposited on ferrogram slide fixture oil flows through it to remove excess oil from the slide [11]. This Ferrogram slide was prepared on dual slide ferrogram maker which was then studied under bi-chromatic microscope.

Fig. 1 Direct Reading Ferrography

(a) (b)

Fig. 2 (a) Dual Slide Ferrogram Maker, (b) Bi-chromatic Microscope

2.2 Quantitative Analysis of Wear particles:

Quantitative analysis of wear particles was carried out by using direct reading ferrography. Direct reading ferrography gives the concentration of large and small size particles, wear severity index, percentage of large size particles [12]. Particle size greater than 5micron is considered as large size particle and less than 5micron is considered as small size particle. Wear severity index and particle concentration is calculated as

WI (Wear Severity Index) = $(DL + DS) * (DL - DS) = (D_L^2 - D_S^2)$

PLP (Percentage of Large Particles) = $\frac{(DL - DS)}{(DL + DS)} * 100\%$

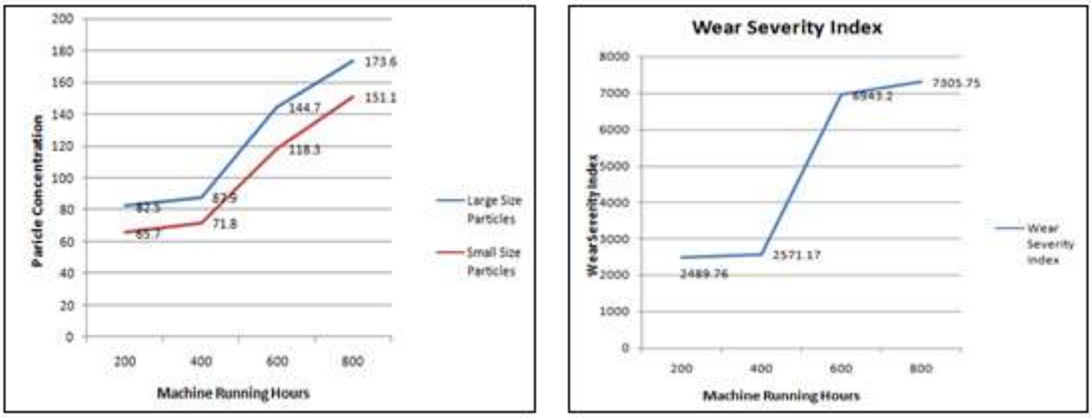
WPC (Wear Particle Concentration) = $\frac{(DL + DS)}{C}$

Where, D_L: Reading of large size wear particle,
D_S: Reading of small size wear particle
C: Dilution Coefficient

Large size and small size particle concentration, wear severity index for collected samples is listed in table 1

Table 1 Wear Severity Index

Machine Running (Hrs)	200	400	600	800
Large Size Particles	82.5	87.9	144.7	173.6
Small Size Particles	65.7	71.8	118.3	151.1
Wear Severity Index	2489.76	2571.17	6943.20	7305.75
Percentage of Large Particles	11.33	10.08	10.03	6.92



(a) (b)

Graph 1 (a) Machine Running Hours versus Particle Concentration (b) Machine Running Hours versus Wear Severity Index

Graph 1 shows the particle concentration and wear severity index versus machine running hours. The concentration of large and small size particles increases with respect to time which indicates that the wear severity increases and there is need for maintenance of gear box.

2.3 Ferrogram Slide Preparation:

Preparation of ferrogram slide is shown in figure 3. The slide was prepared for oil sample collected after 800 hrs of running. After preparation of slide, it was studied under bi-chromatic microscope for shape identification of wear particles [13].

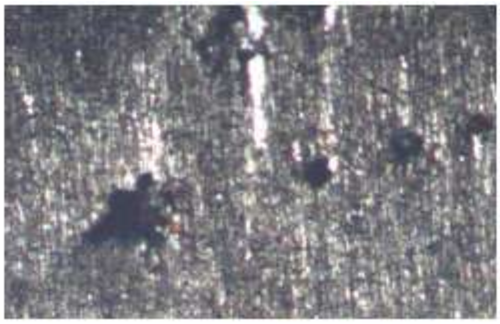
(a) (b)

Fig. 3 (a) Slide Being prepared, (b) Ferrogram Slide

2.4 Microscopic Images of Wear Particles:

Microscopic images were taken at different locations from entry point to exit point at magnification factor of 10x and 50x. Microscopic images showed the presence of normal rubbing wear particles and red oxide in the lubricating oil. Images are as shown in figure 4.

(a) Entry



(b) 20mm away from entry

(c) 40mm away from entry

(d) Red oxide

Fig. 4 Distribution of Particles at different Location on Ferrogram

III. Conclusion

Quantitative and qualitative study was performed on the wear particles from lubricating oil of gear box. Four lubricated oil samples were collected from the gear box for wear test and ferrographic analysis. Larger wear particles stayed at the entrance point of ferrogram slide. Wear severity index increase with time due to increase in wear of gear. Microscopic images showed the presence of normal rubbing wear and red oxide. Red oxide was formed due to the moisture content in lubricating oil. The wear quantitative analysis indicated that there is need to replace lubricating oil with fresh oil. It is difficult to segregate the wear particles from each other which are overlapped, making the analysis of wear particle difficult to understand the microscopic images. The present work depends on expertise which is time consuming and costly, therefore there is need to design an algorithm which will automatically detect the presence of overlapped wear particles in future.

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Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

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