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Wear analysis of mine equipment

A fundamental overview of developments and progress of mathematical models for quantitative estimation of wear in lubricated system are discussed in terms of practical problem of HEMM equipment. A review on extensive modes of wear and their reason is also presented. Their mathematical models related to wear particle concentration, wear rate, total wear, severity of wear, severity Index and total wear amount is considered. The purpose of this paper is to provide an outline of developments taken place over the past three decades, in the field of quantitative estimation of wear debris.

Keywords: *mine equipment, wear, wear modes, lube oil.*

I. Introduction

During last three decades, monitoring of machinery through oil analysis by spectroscopy and ferrography has been employed to diagnosis operating condition and remaining life of components without stopping a system. Table 1 shows methods applied in oil analysis according to particle sizes. In lube oil monitoring some researcher [1], considered large and small particles found in samples separately to analyse wear rate and concentration of wear particles. In an experiment performed by Y. Iwa, bearing metal was rubbed against carbon steel in paraffin oil for the estimation of size, number and volume of wear debris in real time [2]. Typical particles generated in locomotive diesel engines were studied by ferrography for analysing the condition of machines and machine elements [3]. Magnetic separation method and filtering method accompanied by optical and electron microscopy, has been applied to analyse metallic wear debris and contaminants found in fuels (used in diesel engines) [4]. By examining the particle size, shape and surface features of wear particles found in lubricating fluid, associated wear mechanism has been related using image processing by B.J. Roylance and S. Raadnui [5]. Among the various ferrography analysis, heated ferrogram analysis (HFA) technique determine changes in the wear rates of specific engine parts with variation of the oil and coolant temperatures[6]. Engine operating conditions were analysed by severity index which was function of time with function of engine operating variables.

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TABLE I: WEAR PARTICLE ANALYSIS TECHNIQUES BASED ON SIZE [7]

	Method	Particle size range	Type of particle
1	Direct reading ferrography	1-100 µm	Ferromagnetic particles
2	Magnetic filter plug	25-1000 µm	Ferromagnetic particles
3	Patch test	3-100 µm	All types
4	Acid digestion	No limits	All type
5	SEM-EDX	From submicron to macro range	All types

In this paper, various numerical methods used for calculation of HEMM equipment wear are analysed here. Earlier the methods were relying on human expertise. Now a days, development in computer engineering allow us take data more precisely and helps us in doing large mathematical operation efficiently. It has been seen that up to now problems related to quantitative estimation of wear has not been reviewed in terms of their content. Therefore, here in this present work the basic fundamentals mechanism of wear in HEMM and methods for mathematical modelling of wear is analysed in tribodiagnostics.

II. Wear modes

Fig.1 shows the layout of a lubrication system of a typical machine. To study wear in components of a machine, it must be essential to know about the lubrication system of that machine. In general cases, at the end of a cycle, lubricant pass the filters and then go to oil reservoir. So we have to consider that, so that samplings for the quantitative estimation of wear are done before the filter process.

The possibility of failure occurring in a component of machine increases with high speed, high pressure and high temperature. The common wear mechanisms that affect a tribosystem system are [8]:

- Abrasion
- Adhesion
- Fatigue

Table II: Usual wear in machine components

	Component	Type of wear	Reason of wear
1.	Bearing surfaces [9] adhesive wear	Adhesive wear	Adhesive wear occurs when the oil film thickness is insufficient to prevent direct contact between the bearing and the shaft
		Abrasive wear	The contamination of oil either with foreign particles or with wear products
		Surface fatigue wear	Presence of dynamic load and overload
		Corrosive wear	Due to the local heating
		Erosive wear	Erosive wear was manifested by removal of the material due to the fatigue mechanism. the inlet speed of lubricating oil was high, causing fluid erosion of the bearings
		Fracture wear	Static overload or impact loads and/or improper manufacture
		Cavitation wear	Decrease in static pressure
2.	Connecting rod [10]	Fatigue wear	Presence of dynamic load and overload and accumulation of microscopic cracks at, or just below, the working surface
3.	Piston [11]	Abrasive wear	Hardness, friction and heat generation
4.	Piston ring [11]	Abrasive wear	Hardness, friction and heat generation
5.	Piston-cylinder assembly [12]	Abrasive wear	Hardness, friction and heat generation

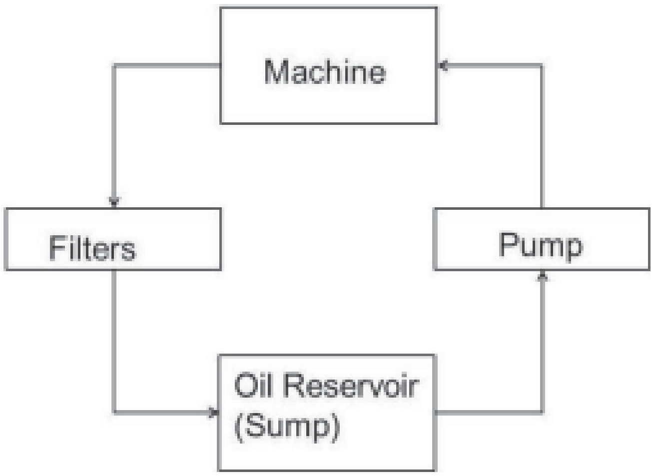

Fig.1 General lubrication system used in typical machines

- Corrosion
- Lubricant breakdown

Abrasion, adhesion, and fatigue involve mechanical damaging of surfaces, corrosion and lubricant breakdown involve chemical reactions. Identification of some or all wear mechanisms occurring in corresponding component of machine enables us to specify the probable reason of failure. Table 2 shows the reason and type of wear in various components of HEMM engine.

III. Mathematical models

There are relatively numerous mathematical approaches to the description of wear in a mechanical system; however, all of them are reduced to one of the following: comparative, parametrical, usage of invariant presentations, and parameterization of visual content.

Anderson and Driver [13] discussed a mathematical model for particle production and decay in the oil of an engine. Here some assumptions are made that X particle/oil cycle is generated and $a_i X$ are removed. Where, a is portioned to X of particles, and also the particle dispersion is sufficiently dilute. An equation is established between the number of cycle and particle concentration.

$$R \geq \frac{ln\,\beta}{ln(1-a_i)} \qquad \text{... ...} \quad (1)$$

In equation 1.1, R is the number of cycle of operation, β is quantity and $\beta 1$. As a is particle removal rate, i subscript refer to the particle size and a is a function of particle size.

The benefit of this model is in estimation the minimum number of cycles to reach equilibrium value of particle concentration. According to the experimental result, a machine with small oil capacity and high flow rate take less time to reach equilibrium state, whereas more time taken in case of larger oil capacity and low flow rate.

The variation of concentration of wear particle with time under different condition such as oil filtration, oil consumption and topping-up were stated mathematically by Kjer [1]. Author divides the particle according to their size as large (e.g. 5 or 10 μm) and small (e.g. 1 μm) roughly and consider them separately of the wear rate modelling. Equation 1.2 is a basic mathematical model for change in wear rate of large particle with assuming of constant wear rate, uniform concentration throughout the oil volume and rate of particle removal is proportional to concentration of particle, with no oil filtration and no oil consumption.

$$\frac{dC_L}{dt} = \frac{P_L - kC_L}{V} \qquad \text{... ...} \quad (2)$$

V(l) is oil volume, C_L (*mgl*$^{-}$) is concentration of large particle, P_L (*mgh*$^{-1}$) is production rate of large particles, *t (h)* is time. The net rate of addition of particle is P_L - *R* (*mgh*$^{-1}$) and $R = kC_L$ where *k* is a removal rate constant. The equation 1.2 shows the concentration of large particle increases with time and reaches a maximum value $C_L(\max) = P/k$, $C_L(\max)$ is independent of volume of oil, time to reach a maximum value of C_L is proportional to volume of oil and inversely proportional to particle removal rate and independent of wear rate.

D. Scott et al [14] purposed formulas for calculation of total wear ($D_L + D_S$), severity of wear ($D_L - D_S$) and severity index $\left(I_s = D_L^2 - D_S^2\right)$. The cumulative values of total wear rate, severity of wear and severity index were plotted against time. Analysis of these trends shows a potential attractive means of machinery condition monitoring.

Y. Iwai et al [2] estimated quantitatively total wear amount during a given duration and introduces an Equation 1.3 to calculate wear volume loss per unit sliding distance.

$$W = \sum_{d_n}^{d_m} \left(\frac{\pi d^2}{4} \times t \times q \times K \right) \quad \text{... ...} \quad (3)$$

W is wear volume; *d* is equivalent mean diameter of wear debris; *t* is thickness of wear debris; *q* is number of wear debris for sliding distance of 1 km, *K* is conversion coefficient $\left(K = \text{Total area} / \text{Area under obsevation} \right)$. The results obtained shows that wear amount calculated by the formula are considered to be reliable and useful in abnormal wear detection in real time.

IV. Conclusion

This overview of development in quantitative estimation of wear debris in practical problem shows an important aspect in tribosystem diagnosis. Numerous examples show successful efficiency of the mathematical models used in wear estimation. There is need to develop methods related to quantitative estimation of wear that will replace the whole manual operation. So that the reliability and efficiency will increase and processing time will be decrease.

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