Proceedings of Malaysian International Tribology Conference 2015, pp. 185-186, November 2015

Lubricating oil deterioration on a four-ball test rig via on-line monitoring

Y. Du, T.H. Wu*, J. Cheng, R.J. Gong

Key Laboratory of Education Ministry for Modern Design and Rotor-Bearing System, Xi'an Jiaotong University, Xi'an, 710049, China.

*Corresponding e-mail: wt-h@163.com

Keywords: Lubricating oil; oil deterioration; on-line monitoring

ABSTRACT – Lubricating oil deterioration in operating machinery is a complicated and dynamic process. With oil ages, its performances attenuate. In this paper, the process of lubricating oil deterioration was investigated with an on-line monitoring system. A four-ball test was carried out to accelerate oil degradation, and three indexes including dynamic viscosity, permittivity and wear particle were monitored to record the aging process. As main results, oil degrades gradually and the selected indexes can characterize oil degradation from different aspects quantitatively.

1. INTRODUCTION

Lubricating oil that contains all the tribological information plays a vital role in life-span performances of various machines [1]. Besides lubricating tribo-pairs, lubricating oil can scavenge wear debris and remove heat from friction surfaces [2]. Due to oxidation and thermal stresses in working conditions, physical and chemical properties of lubricating oil will degrade and eventually cause the increase of wear rate. Therefore, the monitoring of lubricating oil could reveal the deterioration of tribo-system [3]. However, studies on lubricating oil monitoring have been confined in wear debris analysis [4], the degradation mechanism of lubricating oil remains indistinct in principle.

In this study, the laws of lubricating oil deterioration characterized by dynamic viscosity, permittivity and wear particle are investigated to characterize oil aging process. Furthermore, the results from on-line monitoring are examined with off-line analysis to verify the accuracy of on-line data.

2. EXPERIMENT SETUP

To simulate an aging process of lubricating oil under an operating machine, a four-ball test rig is adopted as shown in Fig 1. To obtain real-time data of lubricating oil, a wear debris sensor (OLVF) [5] and an oil property sensor were employed in the oil cycling line. In addition, a temperature control system was set to offer a fixed temperature for the oil property sensor. By doing this, wear conditions and dynamic viscosity and permittivity of lubricating oil can be monitored simultaneously.

To accelerate oil degradation, a test composed with varied loads and speeds was carried out. Details of varied conditions are shown in Table 1. The test was stopped and restarted when working conditions were changed. The waiting time for the intervals lasts a few hours to make sure each test starts with room temperature.

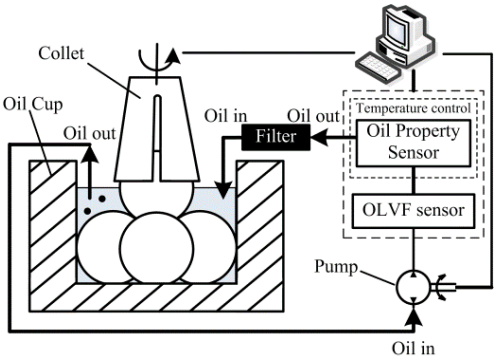

Figure 1 On-line monitoring system for lubricating oil

Table 1 Working conditions for the test

Section No.	Load/N	Rotated Rate/rpm	Time/h
1	1500	1000	6
2	1500	1000	6
3	2000	1000	3.5
4	2000	1000	4
5	2000	1500	1

3. RESULTS AND DISCUSSION

3.1 On-line Data Analysis

The total testing time is 1230 min. The variation data of dynamic viscosity, permittivity and wear particle of lubricating oil are illustrated in Fig 2.

Because temperature had a profound influence on the properties of lubricating oil, the testing temperature was fixed to 50℃ in this paper in order to obtain viscosity and permittivity laws under the same temperature. The test is divided into 5 sections, presented in Fig 2, and at every stop and start points, there are fluctuations on the variation curve of the above three indexes. Some results can be found as:

1) The variation of IPCA (Index of Particle Coverage Area, representing the concentration of wear particles) shows three stages including running-in, normal, and severe stages, which agrees with the typical "bathtub curve". Moreover, the severe stage shows greater wear than the running-in one. In addition, the heavier the loads, the greater the

wear (obtained by the comparison between section 2 and section 3);

2) The variation of permittivity shows a slight reduction at the first section; remains almost a stable condition at sections 2, section 3 and section 4; and sharply increase at the last section;
3) The variation of dynamic viscosity shows an uptrend in the full test. In addition, the heavier the loads, the greater the viscosity variation (obtained from the slopes of the lines at section 2 and section 3).

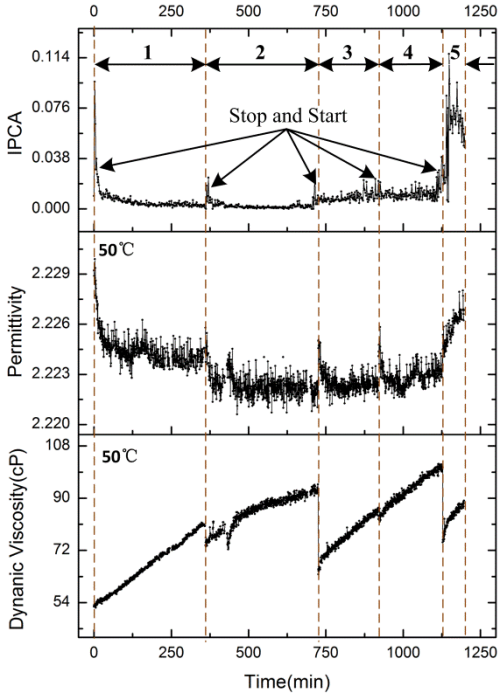

Figure 2 On-line data for lubricating oil.

3.2 Off-line Data Analysis

In order to verify the accuracy of on-line data for lubricating oil, off-line data analysis has been investigated. The results of element composition analyses (ASTM D6595-00) are shown in Fig 3. It can concluded that the main metal-particles in the degradation process are iron (Fe) and silicon (Si), where Fe has been monitored by on-line wear debris sensor, and Si can attribute to the dust in the air. Moreover, the losses of elements Mg, Ca, Zn and P represent the losses of additives of lubricating oil, which explains the decrease of permittivity.

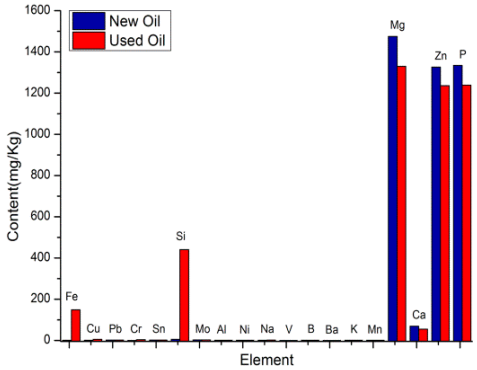

Figure 3 Element composition analyses.

The comparison results between on-line viscosities and off-line viscosities are presented in Table 2. The results of new oil are the measurements of lubricating oil at the beginning of the test, and the results of used oil are the measurements of lubricating oil at the end of the test.

It can be found that after 1230 minutes' severe working, the off-line viscosity of lubricating oil remains almost unchanged, while the on-line viscosity increases a lot.

Table 2 On-line and off-line viscosity.

Sample	On-line Data/cP	Off-line Data/cP
New Oil	52.65	52.64
Used Oil	89.18	51.59

4. CONCLUSIONS

The developed on-line monitoring system is able to detect the changes in process of lubricating oil deterioration, as well as wear conditions in real-time.

The variation laws of lubricating oil degradation can be concluded as follows:

1) The three indexes, wear particle, dynamic viscosity and permittivity, can be monitored to track the aging process of lubricating oil;
2) The wear particle concentration presents three stages including run-in, normal wear and severe wear in the running process, and heavy load will increase the wear rate;
3) The permittivity goes down first on account of losses of additives of lubricating oil, then remains stable afterwards, and finally goes up, which attributes to the acidic oxides produced from the oxidation;
4) The dynamic viscosity increased gradually at each section, and heavy load will lead to great viscosity variation.

5. REFERENCES

[1] P.O. Vähäoja, H.V.S. Pikkarainen, "Trends in industrial oil analysis–a review," *International Journal of Condition Monitoring*, vol. 1, no. 1, pp. 4–10, 2011.

[2] R.M. Mortier, M.F. Fox, S.T. Orszulik, *Chemistry and Technology of Lubricants*, 3th ed. UK: Springer; 2010.

[3] D.C. Schalcosky, C.S. Byington, "Advances in real time oil analysis," *Practicing Oil Analysis Magazine*, vol. 11, no. 2, pp. 28–34, 2000.

[4] T.H. Wu, Y.P. Peng, Y. Du, et al, "Dimensional description of on-line wear debris images for wear characterization," *Chinese Journal of Mechanical Engineering*, vol. 27, no. 6, pp. 1280–1286, 2014.

[5] T.H. Wu, J.H. Mao, J. T. Wang, et al, "A New On-Line Visual Ferrograph," *Tribology Transactions*, vol. 52, pp. 623–631, 2009.