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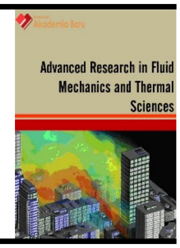

Wear Element Monitoring by Spectrometric Analysis in Automatic Transmission Bus

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ABSTRACT

Heavy duty fleets face many issues regarding lube service intervals, recommended maintenance procedures, and equipment operating costs. Spectrometric analysis is based on the principles of atomic physics whereby an atom emits/absorbs light of a certain wavelength within the ultraviolet and visible region of the energy spectrum if there is an upset in the energy balance within its atomic structure. In this study, transmission fluid samples were taken from automatic transmission gearbox of different mileages. The Atomic Emission Spectroscopy (AES) testing was conducted by using BAIRD MOA spectrometer to detect chemical elements that were present in the transmission fluid. From spectrometric test, wear element concentrations were obtained. The elements traced were phosphorus (P), boron (B), zinc (Zn), magnesium (Mg), calcium (Ca), nickel (Ni), potassium (K), silicon (Si), aluminium (Al), chromium (Cr), copper (Cu), iron (Fe), silver (Ag), tin (Sn) and sodium (Na). These traced elements were grouped into three main categories; group 1 for wear elements with concentration more than 10 ppm (P, B and Zn), group 2 for wear elements with concentration in the range of 0 to 10 ppm (Mg, Ca, Ni, K, Si and Pb) and group 3 for wear elements with concentration less than 0 ppm (Al, Cr, Cu, Fe, Ag, Sn and Na). Based on the results, P which functions as an anti-wear additive has the highest concentration for fresh ATF and is reduced in used lubricant oil.

1.Introduction

Public transportation is one of the important sectors that drive the country's economy growth. Statistic from Road Transport Department Malaysia shows that the total number of vehicles registered in year 2015 is 2.63 million compared to 2.1 million in year 2014. These numbers will definitely increase in the coming years. During vehicle operation, engines will experience wear and tear which can be detrimental to engine operation system and overall performance if they are not maintained and serviced properly. The cost of improper maintenance and services of engine will be escalating overtime. The issue of wear and tear falls under tribology. Similar to mechanical part

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components, the lubricant itself is also competent to change thus leads to failure in lubricants properties. Hence, another concern is on oil changing maintenance.

In common practice, oil changing in buses is maintained by the manufacturer according to the schedule mileage services. This research is to present a study which deals with deploying oil analysis technique to predict wear and tear based on the condition of the transmission fluids found in automatic gearbox. The outcome may lead to some understanding of whether the oil changing schedule is justified. Tung and McMillan stated [1], there are several standard test methods that ensure sustained transmission performance such as physical and chemical properties, stability, and contamination. These methods known as analytical testing and it is an efficient cost-effective tool that is commonly used to detect failure in machine elements without needing to open unnecessary components [2]. In this research, spectrometric analysis was chosen as the preferred technique for measuring the chemical elements present in the transmission fluid. This technique uses the Atomic Emission Spectroscopy (AES) to measure the ppm (parts per million) of wear metals, contaminants and additives in oil samples.

2. Automatic Transmission System

The main concern in this study is the transmission system in engine bus. Transmission, also known as gearbox, is a device to convert shaft speed by increasing the output torque and reducing the revolutions. It is commonly located between the engine and vehicle wheels. Lubricant is important to ensure that the transmission operation works effectively. Thus, systematic lubricant changing schedules tend to prolong the transmission life. Gearbox is generally robust and established device. However, problems do occur due to application error which can be caused by vibration, cooling, mounting and installation, lubrication and maintenance. Misalignment of gear system is the most common problem that occurs in gearbox components. This misalignment leads to high stress on gear surface and excessive heat on the mating surface. In addition, this gear failure causes the lubricants problem in transmission system [3].

The first transmission type used in vehicles is manual transmission system which also known as "sticks shift" or "standard transmission". Since technology in recent decades develops rapidly, the automotive industry has modified the vehicle systems in order to make it more effective and easier to use. Manual transmission system has been modified with gears changing automatically to make automatic geared vehicles easier and this system is known as automatic transmission system.

Automatic transmission system is efficient in the aspects of vehicle safety, comfort, reliability and driving performance [4]. Primary role of automatic transmission system is to transfer torque from input impeller of torque converter via the stator. Automatic transmission uses three main elements during power transmission. The elements are fluid, friction and gears. Usually power continues to be transmitted to the driving wheels during gearshift operation. The fluid then has to lubricate and cool the friction surfaces, lubricate the gears and bearings, act as a hydraulic fluid, prevent the formation of deposits and inhibit corrosion. In power transmission system, 70% of failures are causes by oil contamination, of which 50% are resulted from wear-related problems [5].

3. Oil Analysis Techniques Background

Wear involves removal process of materials from the surface of the moving components due to improper lubrication, contamination, a change in operating conditions and other factors that may cause it. As moving components wear out, they are worn out into billions of tiny particles (which known as wear particles or wear debris) that will get into fluid and be circulated in the system. This process will affect the properties, conditions, physical form, chemical analysis and colour of the lubricants [1]. Wear testing is used to determine the present condition of the equipment. There are many types of wear test methods. The most important is to identify the most appropriate test that meets the objectives of the testing. According to Blau *et al.,* [6], wear testing standards were used to help solve important industrial problems involving sliding wear, abrasive wear, galling, and erosive wear.

Wear characterization in a lubricant can be scheduled and monitored by doing a lubricant monitoring. With suitable testing as AES, the condition of the lubricant and the lubricated equipments can be monitored by collecting data and trending the lubricating oil conditions, which also can prevent damage to machine without interrupting machine operations. Generally, the technique is based on the principles of atomic physics whereby an atom emits or absorbs light of a certain wavelength within the ultraviolet and visible region of the energy spectrum when there is an upset in the energy balance within its atomic structure. Each element present in the burning oil emits a light of characteristic colour and frequency hence translates the intensity of the colours into a computerized readout then presents the results in ppm (parts per million) [6,7]. The main focus of this analysis is to trend the accumulation of small particles of wear metals and elemental constituents of additives, as well as to identify the possible introduction of contaminants.

Latip *et al.,* [8] had done a study on automatic transmission (AT) by determining the wear metals, contaminants and additives using spectrometric oil analysis. The results were analysed between the practical in continuous dynamometer basis and actual travelled distance. It was found that, the presence of wear after period of operating distance in AT can be classified as benign wear and considered as normal wear particles mode. Previous study by Girdhar and Scheffer [9] signified that oil analysis is not only used to analyze the condition of a lubricant but also to monitor the condition of equipment. Macia´n *et al.,* [10] stated that oil analysis is an advanced technique and has been widely used around the world as a suitable method of reducing maintenance costs, improving reliability and productivity.

Spectrometric analysis is one of the main techniques used in particle analysis. It has been proven to be very effective for the maintainability and reliability of oil systems [11]. In the early 1940s, the railroad industry firstly applied this technique to their diesel engines. Within two decades, the U.S. military (Navy, Army, and Air Force) used this method to monitor wear in their diesel, gasoline, and gas turbine engines. Application of this technique had resulted in cost savings, minimized downtime, and increased reliability and fleet readiness.

This is proven by Sejkorová *et al.,* [12] who had discovered the friction wear in motor parts of special military vehicles operated with Ursa super LA 20W/50 oil charge. According to Girdhar and Scheffer [10], a typical report from the spectrometric analysis would list nine major wear metals. A test for twelve elements was conducted for automotive oils. The computer compared the present amount of wear metals with a fresh oil sample and also with samples from similar machines. The computer also compared the results of previous samples taken from the same equipment to establish wear trends. Table 1 shows a list of elements that can be detected using spectrometric analysis and the possible components from where they could originate.

Every lubricant contains additives which can be detected using spectrometric method. Table 2 shows some of the elements that are contained within additives. The detected additive elements can be used to monitor the consistency of the lubricant and its performance for the intended purposes.

Table 1
Elements detected using spectrometric analysis [10]

Wear Elements	Probable Origin
Aluminum	Piston, bearings, blower/turbo charges, pump vanes, thrust washers and bearings, blocks, oil pump bushings, housing clutches, impellers, rotors
Chromium	Rings, roller-tapper bearing, liners, exhaust valves, coolant, rods, spools, gears, shafts, anti-friction bearings
Copper	Bearings, thrust washers, bushings, oil coolers, oil additives, wrist-pin bushings, cam bushings, valve-train bushings, governor, oil pump, steering disc, pump thrust plates and piston, injector shields, wet clutches
Iron	Cylinders, crankshafts, valve train, piston rings, clutch, pistons, rings, gears, bearings, liners, shafts, plates, blocks, camshafts, pumps, shift spools, cylinder bores and rods, piping and components of circulating oil systems
Lead	Bearings, gasoline additives, oil additives
Magnesium	Oil detergent, oil alkaline reserve
Molybdenum	Oil additive, friction modifier
Nickel	Alloy, gear plating, valve guides and ring bands, shafts, anti-friction bearing
Silver	Wrist-pin bushings, anti-friction bearings, silver solder
Tin	Bearings, piston plating, alloy of bronze (cooper/tin), bushings
Silica (Silicon)	Ingested dirt and sand, gasket sealant, oil anti-foam additives, anti-freeze additive
Zinc	Anti-wear oil additive (zinc-dialkyl-dithio-phosphate), galvanized parts in circulating oil systems

Table 2
Elements contained within additives [10]

Wear Elements	Probable Origin
Barium (Ba)	detergent or dispersant additive
Boron (B)	extreme-pressure additive
Calcium (Ca)	detergent or dispersant additive
Copper (Cu)	anti-wear additive
Lead (Pb)	anti-wear additive
Magnesium (Mg)	detergent or dispersant additive
Molybdenum (Mo)	friction modifier
Phosphorus (P)	corrosion inhibitor, anti-wear additive
Silicon (Si)	anti-foaming additive
Sodium (Na)	detergent or dispersant additive
Zinc (Zn)	anti-wear or anti-oxidant additive

4. Methodology

In this research, transmission fluid samples were taken from automatic gearbox bus engines. The transmission fluids were collected from local bus company, Nadi Putra as shown in Figure 1. As recommended by the manufacturer, these transmission fluids need to be changed after 5,000km distance for the first service of a new bus. In the subsequent services, the recommended distance interval is 50,000km. Due to the constraint in getting oil samples from different mileages from one single bus, the oil samples were collected randomly but have a same daily operation routine, type of bus, fluid transmission gearbox used and gearbox specification.

Fig. 1. Gearbox bus from Nadi Putra bus engine

The oil samples were taken with an interval of 5,000km, 30,000km, 50,000km, 80,000km, 180,000km and 300,000km of bus operation. These oil samples were taken during gearbox schedule services. The samples were collected from the transmission fluid sum and kept in clean bottles using suction pump. Transmission fluid samples in each bottle were labelled according to the bus transmission and mileage. For this study, 20 samples were taken from different intercity services busses with the same model of gearbox. It is not feasible to take 20 samples from the same bus because this will take a longer time to reach the maximum distance required that is 200,000km distance for automatic gearbox.

The AES testing is conducted by using BAIRD MOA spectrometer as shown in Figure 2. Transmission fluid sample is prepared in the excitation chamber as it has been cleaned from any dirt to ensure the accurate readings. Rod electrode is installed with its tip rest on the disc electrode to its fully down position and the vessel containing the transmission fluid is placed on the platform. When the setting is completed, the excitation compartment door is securely closed before starting the burning process which takes approximately 39 seconds. This technique involves “burning” a small quantity of an oil sample in an oven using a high voltage electric spark. The sparks excite the atoms of the element and emit radiant energy. The light from the excited atoms is passed into the optical system (spectrometer). All elements emit light at specific and characteristic wavelengths. The brightness of the light emitted by an element is measured by a photo detector that converts light energy into electrical energy. By comparing the intensity of sample spectral lines with those from standards, the concentration in parts per million (ppm) of the elements in a sample is determined.

Fig. 2. BAIRD MOA Spectrometer

5. Results and Discussion

Transmission fluid samples obtained were categorized based on mileages: 5,000km 30,000km, 50,000km, 80,000km, 180,000km and 300,000km. The concentrations of elements in transmission fluid at different mileage were determined. The elements in Table 3 to Table 5 were grouped into three main categories; (1) wear element concentration more than 10 ppm, (2) wear element concentration in the range of 1 to 10 ppm, and (3) wear element concentration less than 1 ppm. According to the traced elements, phosphorus(P), boron(B) and zinc (Zn) belong to the first group (>10 ppm) as indicated in Table 3 whereas in Table 4, magnesium (Mg), calcium (Ca), nickel (Ni), potassium(K), silicon (Si) and lead (Pb) fall in the second group (1-10 ppm). For Aluminum (Al), Chromium (Cr), Copper (Cu), Iron (Fe), Silver (Ag), Tin (Sn) and Sodium (Na), these elements belong to the third group (<1 ppm) as shown in Table 5.

Table 3
Wear element concentration more than 10 ppm

Elements	Wear (ppm)						
	Fresh ATF	5,000km	30,000km	50,000km	80,000km	180,000km	300,000km
P	258	221	222	220	228	239	233
B	94	71	74	76	73	57	56
Zn	46	36	37	36	37	40	38

Table 4
Wear element concentration between 1 to 10 ppm

Elements	Wear (ppm)						
	Fresh ATF	5,000km	30,000km	50,000km	80,000km	180,000km	300,000km
Mg	5	1	1	2	5	16	15
Ca	5	84	87	82	90	81	80
Ni	2	2	2	2	2	2	2
K	2	2	3	2	3	3	3
Si	2	2	3	2	2	3	4
Pb	1	53	20	11	10	18	32

Table 5
Wear element concentration less than 1 ppm

Elements	Wear (ppm)						
	Fresh ATF	5,000km	30,000km	50,000km	80,000km	180,000km	300,000km
Al	0	5	4	3	5	5	6
Cr	0	0	0	0	0	1	1
Cu	0	61	20	45	89	81	76
Fe	0	31	18	16	19	138	212
Ag	0	3	2	2	3	13	12
Sn	0	5	1	4	9	7	7
Na	0	2	1	0	1	0	0

From the results in Table 3, elements of P, B and Zn have the highest concentration rate in fresh and used ATF. Despite to B and Zn, P contributes the highest concentration which leads to degradation of additives during high temperature operation. It can be observed that, after certain mileage, the concentration of P had decreased. This has been suggested by Rahimi [13], that the reduction is caused by the degrading products that get filtered during oil circulation.

As shown in Table 4, the elements of Mg, Ca and Pb in used ATF has the highest concentration compare to fresh ATF. A sudden increment in the concentration may indicate failure or excessive wear of bus engine components as suggested in Table 1 which the concentration in Mg may come from oil detergent and oil alkaline reserve whilst Pb from bearings, gasoline additives and oil additives. This as well has been studied by previous researcher [14], which found Mg comes from cylinder liner, gear box housings in aircraft engines, hard water and lube oil additive. As for the element Ca, it is possibly from hard water, detergent additive, oxidation inhibitor and road salt while Pb from bearings, fuel blow by, thrust bearings, bearing cages and bearing retainers.

Referring to Table 5, the elements concentration of Fe and Cu were presents in used ATF after running for certain mileages as it shows no rate concentration for the new ATF. It was observed that Fe is the most common wear metal particles in ATF. From the previous researchers, H. Kaleli and I. Yavasliol [15] stated that the acceptable wear concentration limit for Fe is in between 40 to 200 ppm and the concentration that higher than 100 ppm might lead to failure in the system basis. Data from Table 5 presented that the Fe concentration for 180,000km and 300,000km is more than acceptable limit. Hence, as suggested in Table 1, the wear concentration may be caused from engine block, cylinders, gears, cylinder liners, valve guides, wrist pins, rings, camshaft, oil pump, crankshaft, ball and roller bearings, rust. The suggested acceptable limit for Cu is between 5 to 40, therefore it can be noticed that the concentration of Cu was higher than 20 ppm in used ATF except for 30,000km. Due to this high wear concentration, it has been proposed to test and analyse the elements in terms of oxidation level and oxidative degradation of the lubricant. These outcomes meet the finding by S. Abdul Latip *et al.,* [8, 16] which stated that the elements of Fe and Cu were the wear metals that commonly found in large quantities in used lubricant oil.

Metal elements in transmission fluid come from different sources such as wear, contamination and additives. Generally, wear metal particles are the output of friction or corrosion of the engine components. Contamination is due to dirt, leaks or remaining. Additives tend to reduce friction and wear, increase viscosity, provide resistance to corrosion and aging engine parts.

6. Conclusions

Spectrometric test results were grouped into three main categories; wear element concentration more than 10 ppm, wear element concentration in the range of 0 to 10 ppm, and wear element concentration less than 10 ppm. Spectrometric test analysed the transmission fluid composition and record changes between fresh and used transmission fluid. Based on the results, it can be concluded that through different intervals of operation mileage, these changes lead to an adverse effect on engine life and components. From spectrometric test, wear element concentrations were obtained. These traced elements were grouped into three main categories; group 1 for wear elements with concentration more than 10 ppm (P, B and Zn), group 2 for wear elements with concentration in the range of 0 to 10 ppm (Mg, Ca, Ni, K, Si and Pb) and group 3 for wear elements with concentration less than 0 ppm (Al, Cr, Cu, Fe, Ag, Sn and Na).

Based on the results, P which functions as an anti-wear additive has the highest concentration of 258 ppm for fresh ATF. The reduction of P in used ATF (221-239 ppm) is due to additives degradation during high temperature bus engine operation. The higher concentration of Mg, Ca, Pb, Zn and Si in used ATF might indicate failure in transmission system. For Ca and Pb, the readings of used ATF were much higher than those of fresh ATF for all cases in the range of 80-90 ppm and 10-53 ppm respectively. The presence of Fe (16-212 ppm) and Cu (20-89 ppm) in used ATF indicates wear which may come from engine block, cylinders, gears, cylinder liners, valve guides, wrist pins, rings, camshaft, oil pump, crankshaft, ball and roller bearings, rust, bushings, injector shields, coolant core tubes, thrust washers, valve guides, connecting rods, piston rings, bearings, sleeves, and bearing cages.

References

[1] Tung, Simon C., and Michael L. McMillan. "Automotive tribology overview of current advances and challenges for the future." *Tribology International* 37, no. 7 (2004): 517-536.

[2] Hurtová, Ivana, and Marie Sejkorová. "Analysis of engine oils using modern methods of tribotechnical diagnostics." *Perners Contacts* (2016): 47-53.

[3] Asi, Osman. "Fatigue failure of a helical gear in a gearbox." *Engineering failure analysis* 13, no. 7 (2006): 1116-1125.

[4] Akple, Maxwell S., Richard Fiifi Turkson, Robert Biscoff, Bartholomew K. Borlu, and Augustine A. Apreko. "Driver Preference for Automatic or Manual Transmission Systems for Vehicles: A Case Study in Ghana."

[5] Zheng, Changsong, Pei Liu, Yong Liu, and Zhouli Zhang. "Oil-based maintenance interval optimization for power-shift steering transmission." *Advances in Mechanical Engineering* 10, no. 2 (2018): 1687814018760921.

[6] Blau, Peter J., and Kenneth G. Budinski. "Development and use of ASTM standards for wear testing1." *Wear* 225 (1999): 1159-1170.

[7] van de Wiel, Henk J. "Determination of elements by ICP-AES and ICP-MS." *National Institute of Public Health and the Environment (RIVM). Bilthoven, The Netherlands* (2003): 1-19.

[8] Latip, Syazuan Abdul, Salmiah Kasolang, Siti Khadijah Alias, Syarifah Yunus, Abdul Hakim Abdullah, and Norhisyam Jenal. "Wear Elemental Spectrometric Quantitative Analysis of Used Perodua Automatic Transmission Fluid-3 Series (ATF-3)." *Procedia Engineering* 68 (2013): 193-198.

[9] Scheffer, Cornelius, and Paresh Girdhar. *Practical machinery vibration analysis and predictive maintenance*. Elsevier, 2004.

[10] Macian, V., B. Tormos, P. Olmeda, and L. Montoro. "Analytical approach to wear rate determination for internal combustion engine condition monitoring based on oil analysis." *Tribology International* 36, no. 10 (2003): 771-776.

[11] Akintunde, D. "Spectrometric Oil Analysis–An Untapped Resource for Condition Monitoring." *AU JT* 12, no. 2 (2008): 107-114.

[12] Sejkorová M, Singer J, Pužejová D, "Analysis of The Operational Wear Process of Military Technology Oils with a View to the Instrumental Methods," *Machines, Technologies, Materials,* no. 2-3 (2007): 51-53.

[13] Rahimi, Behnam, Abolfazl Semnani, Alireza Nezamzadeh-Ejhieh, Hamid Shakoori Langeroodi, and Massoud Hakim Davood. "Monitoring of the physical and chemical properties of a gasoline engine oil during its usage." *Journal of analytical methods in chemistry* 2012 (2012).

[14] Nadkarni, R. A. *Spectroscopic analysis of petroleum products and lubricants*. West Conshohocken, PA, ASTM International, 2011.

[15] Kaleli, Hakan, and Irfan Yavasliol. "Oil ageing-drain period in a petrol engine." *Industrial Lubrication and Tribology* 49, no. 3 (1997): 120-126.

[16] S. Abdul Latip,S. Kasolang, Z. Michael, A. N. Adnan, "Oil analysis of used Perodua automatic transmission fluid (ATF-3) using spectrometric technique", *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 28, no 1 (2016): 17-25.