ANALYSIS OF AUTOMATIC TRANSMISSION USING FOURIER TRANSFORM INFRARED (FTIR) SPECTROCOPY

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Abstract

Automatic Transmission (AT) system is efficient in the aspects of vehicle safety, comfort, reliability and driving performance. The objectives of this paper are to collect the oil samples from AT systems of engine bus according to manufacturer's recommendations and analyse collected oil samples using oil analysis technique. The sample transmission fluid which was taken from the AT gearbox has been experimentally analyzed. The oil samples were taken with an interval of 5,000km, 30,000km, 50,000km, 80,000km, 180,000km and 300,000km for AT bus operation. These samples then have been analyzed by comparing between new and used transmission fluid using Fourier Transform Infrared (FTIR) spectroscopy. Oil analysis by FTIR is a form of Predictive Maintenance (PdM) to avoid major failure in machine elements. Most machine elements are not easily accessible in the transmission system. Having a reliable technique would avoid the needs to open the components unnecessarily, hence, help to prevent catastrophic failure which are very costly, and ease of regular monitoring. In order to identify the major failures of automatic gearbox, forecasts can be made regarding the lube transmission fluid analysis test. By using this test, the minor problems can be determined before they become major failures. At the end of this research, the wear particles profile for interval mileage of AT system was obtained.

Keywords: Wear, Automatic Transmission (AT), Transmission fluid, Fourier Transform Infrared (FTIR), Oil analysis.

1.0 INTRODUCTION

Automatic Transmission (AT) system is efficient in the aspects of vehicle safety, comfort, reliability and driving performance (Biscoff, Akple, Turkson, Klomegah, & Apreko, 2013). Primary role of AT system shown in Figure 1 is to transfer torque from input impeller of torque converter via the stator as it uses three main elements during power transmission such as fluid, friction and gears. Usually power continues to be transmitted to the driving wheels during gearshift operation where 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. AT is normally designed for a special torque and speed range. Based on the data, the first step in the design process is to make the basic construction of the automatic transmission including an analysis of all axles, bearings, gear wheels, clutches or torque converters.

Figure 1 Automatic transmission used in bus engine

Wear has been recognized as the phenomenon of material removed from a surface due to interaction with a mating surface (Enzhu et al., 2013). According to Kimura, Sekizawa, & Nitanai (2002) almost all machines loss their durability and reliability due to wear. Wear processes are generally characterized by four basic elements : (a) the quantitative level, defined by the total volume of wear particles which shows the wear extent in the interacting areas; (b) the severity level which is correlated with the size distribution of wear particles and indicates the wear modes; (c) the morphological distribution of significant particles which indicates typical wear mechanism (adhesion, abrasion, corrosion etc.) responsible for damages; (d) the identification of materials of wear particles to localize the sources of the particle.Wear rate changes are depending on operating condition and material selections (Gagg & Lewis, 2007). These results mean that design of operating condition and material selection are the key of controlling wear. As one way to meet these requirements, wear maps has been proposed for prediction of wear modes (Basu, Sengupta, & Ahuja, 2006). A wear maps is considered as one of the best descriptions of tribological conditions and it is useful in selecting materials in a wide range of operating conditions. Meigh (2000) clarify that there are four major types of wear which are adhesive, abrasive, fatigue, and corrosive.

IR spectroscopy is one of the common and important spectroscopy analytical techniques used by scientists mostly in organic and inorganic fields. This technique also has been used widely for material analysis in laboratory. The main function of IR spectroscopic analysis is to determine the chemical functional groups in the sample. Different functional groups absorb characteristic frequencies of IR radiation. Using various sampling accessories, IR spectrometers can accept a wide range of sample types such as gases, liquids, and solids. Thus, IR spectroscopy is an important and popular tool for structural elucidation and compound identification (Hsu, 1997). FTIR analyses the differences in chemical and physical composition between the fresh and used oil. As a result, fresh and used oil carried out in absorbance basis to evaluate the constituents of the fresh oil sample and their changes in the constituents after certain period of operation (Upadhyay & Kumaraswamidhas, 2013). Infrared absorption typically analyzed using FTIR is summarised in a chart of characteristic group absorbance in Table 1 introduced by Garry & Bowman (2007) IR spectrum looks quite complex because the bond vibrations create absorption bands.

Table 1 Concentration of functional groups

Characteristics (Group)	Absorption (approx. cm^{-1})
Soot	2000
Oxidation (carbon)	1700
Nitration	1630
Sulfation	1150
Water	3400
Diesel fuel	800
Gasoline	750
Antifreeze (glycol)	880
Antiwear additive	960

Many of the absorbance groups vary over a wide range because the bands arise from complex interacting vibrations within the molecule as shown by Upadhyay & Kumaraswamidhas (2013) in Table 2. IR spectrum can be split into the functional group region and the fingerprint region. Functional group presents region from 4000 cm^{-1} to 1300 cm^{-1} and can be identified as unknown compound in this band. Region from 1300 cm^{-1} to 400 cm^{-1} can be found in fingerprint region. These bands are only used to compare the spectra of one compound to another.

Table 2 IR Absorption Regions

Bond Type	Absorption Region (cm^{-1})
C-O	1300 - 800
C-C	1300 - 800
C-N	1250 - 1000
C=C	1900 - 1500
C=O	1850 - 1600
C≡C	2150 - 2100
C≡N	2240 - 2280
C-D	2250 - 2080
C-H	3000 - 2850
O-H	3800 - 2700

In functional group, IR spectrum can be assigned as bonds to hydrogen; N-H, O-H and C-H triple bond; C≡C and C≡N and double bond; C=C, C=O and C=N. In fingerprint region, there is only single bond; C-C, C-O and C-N.

These results (used transmission fluid) are calibrating with pure and known substances (fresh transmission fluid) by using the wavelengths that are absorbed and correlated in Table 1 and Table 2. One advantage to FTIR analysis is that the user is provided with both qualitative and quantities results. This will not only identify the different functional groups present in the sample, but it will also give some measures to the percentage contained.

This research focuses on AT fluid. Since most of machine elements are not easily accessible in transmission system, oil analysis testing is needed to analyze the fluids. This enables identifications of

types of contaminant present and materials they are made out of, which can be matched with the parts that are wearing out.

2.0 EXPERIMENTAL METHOD

In this research, the transmission fluids samples were taken from automatic gearbox in bus engines. The transmission fluids were collected from local bus company which is Nadiputra at Putrajaya. As recommended by the manufacturer, these transmission fluids need to be changed after 5,000km distance for the first service of a new bus. For 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 the same daily operation routine, type of bus, fluid transmission gearbox used and gearbox specification.

The oil samples were taken with an interval of 5,000km, 30,000km, 50,000km, 80,000km, 180,000km and 300,000km for automatic 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 labeled 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.

3.0 RESULT AND DISCUSSION

This section provides the FTIR spectroscopy analysis results for the AT in engine bus. All samples were analyzed using OMNIC Spectra in order to identify the chemical information in absorbance basis of materials present before and after usage at certain mileage. The spectral outcomes of the used transmission fluid were analyzed and later compared to those of the fresh transmission fluid as a baseline.
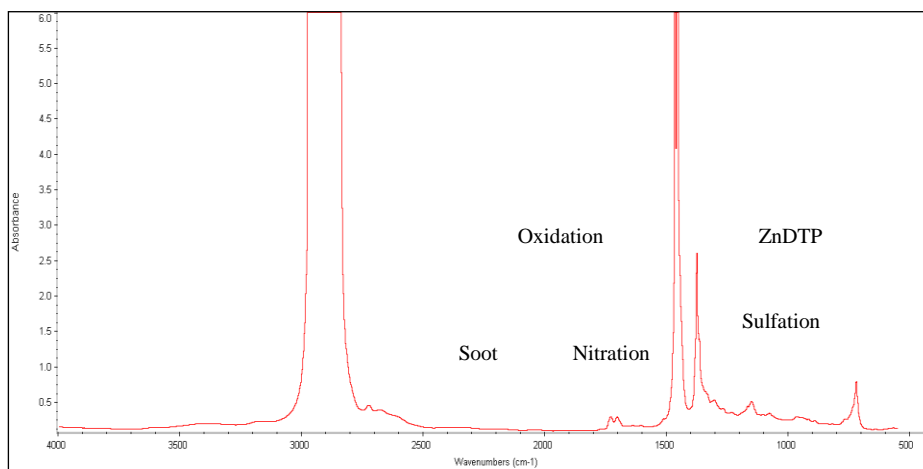

Figure 2 FTIR result of fresh ATF

The result of FTIR for fresh ATF is shown in Figure 2. From the figure, several peak of fresh ATF were observed which are soot, oxidation, nitration, sulfation and ZnDTP. These peaks were identified using Infrared Correlation Chart given by Thermo Scientific. For the wavenumber between 2800 cm^{-1} to 3000 cm^{-1}, the elements expected were from aromatic C-H, bonded OH in carboxylic acid, amino acid, bonded NH or NH2 and Phosphorus Hydroxides. Wavenumber 1450cm^{-1} indicates the elements of pyridines contain triazine and -CH2 functional group of Aliphatic CH- methylene. For the wavenumber of 1350cm^{-1}, the elements are epoxide, sec amide contains sulphone or sulphonamide, nitro functional group –NO2, NO3 Nitrate and NH4 Ammonium.
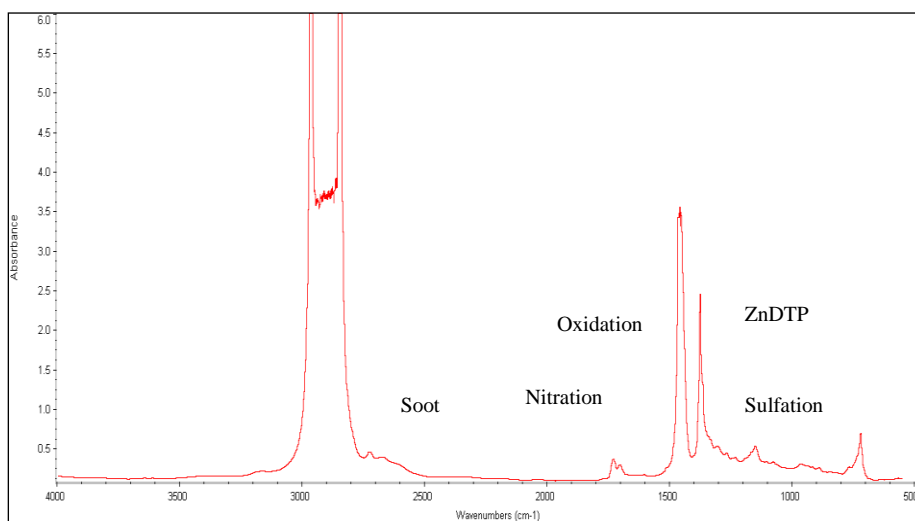
Figure 3 FTIR Result of Degraded ATF after 5,000km
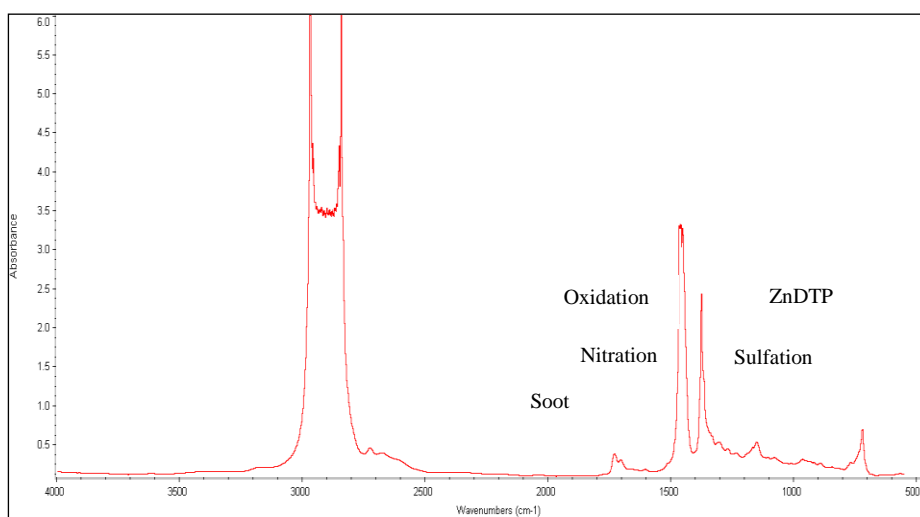
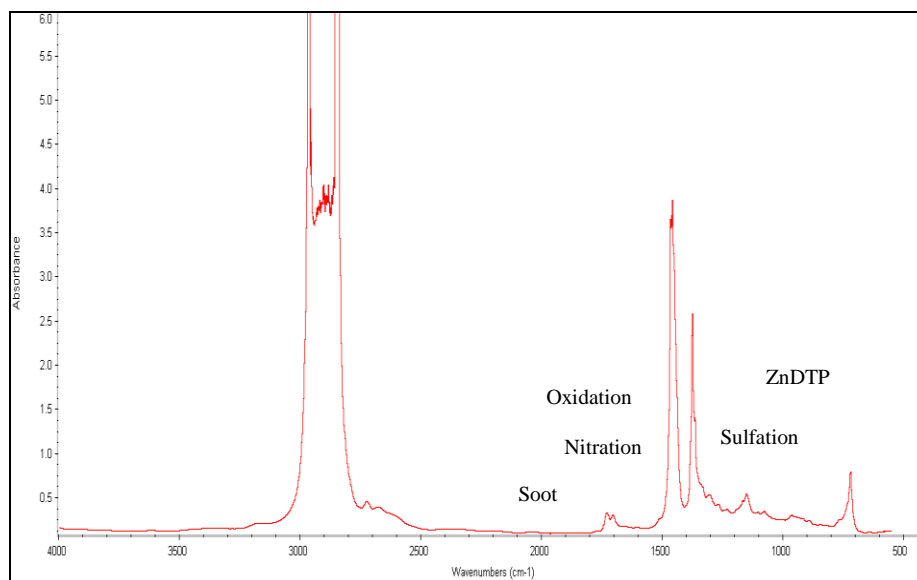**Figure 4 FTIR Result of Degraded ATF after 30,000km**

Figure 5 FTIR Result of Degraded ATF after 80,000km

Wavenumber profile of used lubricant for 5,000km, 30,000km and 80,000km are shown in Figure 3, Figure 4 and Figure 5. These wavenumber profiles have similar characteristics as fresh ATF shown in Figure 2. Based on Figure 3, there five peaks were observed which were at 2000 cm^{-1}, 960 cm^{-1}, 1700 cm^{-1},1630 cm^{-1}and 1150 cm^{-1}. Based on Table 1, the associated elements were determined as it was found that, the peaks correspond to soot, ZDDPs, oxidation, nitration and sulphur. Similar peak profiles were also observed in the case of 30,000km in Figure 4 and 80,000km in Figure 5. The results of ATF for different mileage cases were summarized in Table 3. The index number for five functional groups; soot, oxidation, nitration, sulfation and ZnDTP were categorized into 6 cases based on mileages and presented in Table 3.

Table 3 Data results obtained by FTIR spectroscopy

Elements	Concentration (A/.1mm)						
	Fresh ATF	Case 1 5,000km	Case 2 30,000km	Case 3 50,000km	Case 4 80,000km	Case 5 180,000km	Case 6 300,000km
Soot	0.35	0.36	0.35	0.34	0.33	0.32	0.33
Oxidation	1.77	2.38	2.48	2.13	2.05	1.93	1.99
Nitration	0.57	0.6	0.67	0.69	0.65	0.67	0.71
Sulfation	2.93	3.62	3.69	3.91	3.86	3.59	3.32
ZnDTP	-0.06	0	-0.02	-0.07	-0.06	-0.09	-0.09

The soot elements which known as carbon black change regularly for every case of ATF. Refer to Table 1, soot absorbance intensity was observed at 2000 cm^{-1} peak. Changes in soot levels show that there was a problem in transmission fluid. Soot contamination in lubricants fluid caused the wear to increase in system components. This failure led to reduction in lubricants service life and increased in the frequency of lubricants changing period. It was reported by Hu et al. (2013) that soot obtained in lubricants fluid tend to reduce the anti-wear effect of ZDDPs. Based on results in Table 1, anti-wear is observed at 960 cm^{-1} peak. These additives were the key to its ability to reduce bearing corrosion and prevent direct metal-to-metal contact by forming a coating on metal surfaces activated by frictional heat (Ahmed & Nassar, 2011). Hu et al. (2013) reported that the combination of ZDDPs and carbon black produced higher wear

rate in lubricants fluid sample. From the report, it is revealed that lubricants containing carbon black indicated severe wear compared to lubricants containing carbon black itself.

Based on Table 3, it is shown that oxidation concentration for ATF increased for every case. In Table 1, oxidation absorbance was observed at 1700 cm^{-1} peak. Oxidation indicates that the lubricant has chemically changed due to reaction with oxygen. According to Ahmed et al. (2011), oxidation process causes the lubricants to thicken. Eventually, as oxidation increases, the fluid begins to lose its lubricating properties and also increase corrosion and viscosity. The main factor contributing to this increment is high operating temperatures or overheating. Somehow it is also likely caused by extended lubricants change intervals (A.Tribology, n.d.).

From the previous study, Marinović, Jukić, Doležal, Špehar, & Krištović (2012) stated that the organic compounds exposed to high temperatures and pressures formed oxidation and nitration products due to the presence of oxygen and nitrogen.

Nitration absorbance intensity was observed at 1630 cm^{-1} peak. Based on the results, nitration tends to occur in ATF. Nitration is an undesirable condition where its reaction forms two types of nitrogen compounds namely organic nitrates and nitro compounds. These two compounds are an independent of the oxy-products that lead to lubricants oxidation. Nitration generally caused by ambient air conditions, spark timing, and final combustion temperature. From the field test, (Nitration of lubricating oil and benefits of oil analysis, n.d.) it is shown that nitration increases when ambient air temperatures increase or loads are higher. The result in this study may suggest that AT components of the bus engine deployed in this study were likely to operate at high temperature and high load. Glycol works as a coolant for AT components. In Table 1, glycol absorbance intensity was observed at 880 cm^{-1} peak. As suggested in ASL Tribology (A.Tribology, n.d.), glycol obtained from transmission fluid might cause wear, corrosion, sludging and lubricant breakdown in transmission system. Contaminations by glycol caused the lubricants viscosity to increase and this may lead to higher friction on interacting surfaces and hence more power loss. Based on the previous study, Fitch (2001) has reported that coolant contamination in transmissions and hydraulic fluids usually showed an increase in oxidation. Coolant leak in the cooling system produced water and glycol which can cause a rapid sludging and aging of oil.

The last element observed is sulphur which is present as additive in most lubricants. In this study, sulphur absorbance intensity was observed at 1150 cm^{-1} peak as shown in Table 1. Sulfate material was a result of the oxidation of sulfur from the base oil and additives. In Table 3, the used ATF shows the enhancement value of sulphur index number compared to fresh transmission fluid. The presence of sulphur was associated with viscosity increase, varnish, sludge and sedimentation formation, base oil breakdown, additive depletion and depletion of basic reserve, loss of lubricity and decrease in Total Base Number (TBN). Some of possible sources for high sulfation were crankcase blow-by, water presence in the crankcase, incorrect operating conditions and poor combustion. Hence, the bus engine deployed in this study might have one or more problems described in ASL Tribology (ASL Tribology, n.d.).

4.0 CONCLUSION AND FUTURE WORKS

From the results, spectral outcomes were obtained and analyzed. The results pointed out the presence of soot, ZDDPs, oxidation, nitration, sulphur, glycol and diesel fuel at peak intensity of 2000 cm^{-1}, 960 cm^{-1}, 1700 cm^{-1}, 1630 cm^{-1}, 1150 cm^{-1}, 800 cm^{-1} and 1150 cm^{-1} respectively. The present of soot suggests that transmission components in contact with MTF are at higher risks of experiencing abrasive wear when the soot level and the load become excessively high. ZDDPs are anti-wear additives and help to reduce bearing corrosion and prevent direct metal-to-metal contact. However ZDDPs when combine with carbon

black tend to induce higher wear rate. Increased oxidation may cause lubricants to lose its lubricating properties and hence increase corrosion and friction. Nitration results suggest that automatic transmission components of the bus engine deployed in this study were likely to operate at high temperature and high load. The presence of sulphur may indicate viscosity increase, varnish, sludge and sedimentation formation, base oil breakdown, additive depletion and depletion of basic reserve, loss of lubricity and decrease in Total Base Number (TBN). Glycol obtained in the result might suggest indicate wear, corrosion, sludging and lubricant breakdown in bus engine gearbox system.

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