Analysis of automatic transmission fluid in CNG bus engine by ferrographic technique

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Abstract: Public transportation helps to reduce road congestions, gasoline consumptions, saves money and also enhances personal opportunities. However, maintenance problem is a concern in public transportation that could cause disruption of service. In this study, this issue had been addressed in order to help prediction of wear so that the problem could be predicted before it happens. This study looks into the Compressed Natural Gas (CNG) Engine of Nadi Putra bus on the inconsistency range of mileage in changing the Automatic Transmissions Fluid (ATF). The objective of this project is to study gearbox conditions in a bus (Nadi Putra) in term of lubrication and wear. Ferrographic analysis was carried out in order to determine types of wear particles and suitable range of mileage for the bus to change the ATF by analyzing the sample of transmissions fluid taken from bus gearbox. Optical microscopy and Predict Chart were used to characterize and identify sample in where groups. It was observed that the rolling-element fatigue and cutting wear were major findings in all samples oil analysis tested.

1. Introduction

The integration of natural gas vehicles into the transportation sectors are promoted by the availability of domestic natural gas reserves, improved fueling infrastructure, and state incentives. Many heavy-duty fleet applications such as refuse trucks, transit buses, school buses and delivery trucks have transformed to use compressed natural gas (CNG) instead of diesel. This is due to attractive features of CNG.

The natural gas used in natural gas vehicles (NGVs) is the same gas used in domestic sector for cooking and heats. CNG is produced by compressing the conventional natural gas to less than 1% of the volume it occupies at standard atmospheric pressure and stored in rigid container at a pressure of 200-248 bars (2900 – 3600 psi) [1]. Natural gas is characterized by soot-free combustion when used in internal combustion engines producing a clean-burning fuel. These characteristics make natural gas is more environmental-safe compared to diesel [2].

Natural gas is becoming one of the most important resources of energy and recently shares 23% of world primary consumption [3]. The rise of oil prices has given opportunity to CNG vehicles to prove itself as a cheap and cleanest fuel and making the countries more energy sovereign by reducing the dependency on oil.

The transport type, distance, and means of transport are among the factors to be considered in using different fuels and alternative drives and among others, urban areas hold the greatest possibilities of using different alternative fuel. This is going back to the advantages of CNG whereby applying...
natural gas to power buses has a positive impact on eutrophication, acidification, and photochemical ozone creation potential [4] and considerably limits elemental and organic carbons, and PAHs [5]. Relatively large stores are also an advantage of natural gas.

Wear is one of the common failures occur in Natural Gas Vehicles. It is crucial to prevent this failure from happen since the source of failure could be predicted by using Ferrography Techniques.

Ferrography Technique (FT) is a method where particles will separate on a glass slide based on the interaction between an external magnetic field and the magnetic of the particles suspended in a flow stream. Levi and Eliaz [6] claimed that a reliable procedure was developed for condition monitoring of an open-loop oil system, based mainly on Analytical Ferrography in the study of involving closed loop dynamic system. The origin, mechanism and level of wear could be estimated by determining the number, shape, size, texture and composition of particles on the ferrogram. This technique was described in detail by previous researchers [7, 8].

In this present study, oil analysis by FT has been used to identify the presence of material composition. This investigation was conducted on a series of CNG Gearbox transmission with the purpose of correlating ferographic results with the actual wear conditions and compare wear evolution in a gearbox of the same type.

2. Methodology

In this research, the oil samples were collected from a local bus company, Nadi Putra buses which has shown in Figure 1(a). This oil samples were taken from CNG bus gearbox (DIWA.3 Automatic Transmission) as shown in Figure 1(b). The transmission fluid used in this gearbox was red dyed fluid, Caltex Texamatic 7045.

![Figure 1. (a) Nadi Putra Bus (Putrajaya) and (b) Nadi Putra Bus Engine Gearbox](image)

In this study, the oil sample analysis was performed by using Ferrogram Maker (FM-III) which provided a strong magnetic field that used to separate the wear debris from the oil sample on the ferrogram glass slide. The testing process started with prepared 3ml of the lubricant fluid and 3ml of n-Heptane by mixed it on shaker machine. This oil sample then was run on FM-III and details analysis using an optical microscope (Olympus BX51M). Both of the FM-III and optical microscope were shown in Figure 2.
3. Results and Discussion

The results of Ferrographic test were analysed using optical microscope and the observation is captured. The results can be categorized into different groups based on the mileage. There are 4 different mileage tested: (1) 20000 km, (2) 30000 km, (3) 40000 km, and (4) 50000 km.

Figure 3, Figure 4, Figure 5, and Figure 6 shows images of wear particles morphology that presents on the oil sample slide for mileage 20000 km, 30000 km, 40000 km and 50000 km respectively. The wear particles morphology obtained using Optical Microscope were then identified and compared to the Predict chart. This was done for comparison purposes to get the most similar profile from the chart on which the wear mechanism was approximated.

Figure 3(a) shows a normal rubbing wear whilst Figure 3(b) shows a particle typical of the break-in period for components having a ground or machined surface finish with 500X magnification. These particles are formed in decreasing quantity until the original finishing marks are covered or worn away. Figure 3(c) is an image of fine cutting wear particles with a 500X magnification. The height of the largest particle is greater than the depth of focus of the optical microscope. The bent portion above the glass substrate cannot be brought into the focus simultaneously with the substrate.

In Figure 3(d), a typical distribution of particles with 200X magnification during the normal running of rolling-element bearings were observed. These particles were generated by rolling-element bearing fatigue spherical. In Figure 3(e), scuffing wear particle with 500X magnification were identified while Figure 3(f) shows the typical of severe wear particles with dissimilar magnification of 200X. The high ratio of large-to-small particles is indicative of stress levels far above that which the surface can tolerate.
Figure 3. Image of wear morphology at mileage 20000km

Figure 4(a), (b), (c), (d), and (e) presents a normal rubbing wear (500X magnification), cutting wear (200X magnification), rolling-element fatigue wear (500x magnification), gear fatigue wear (500x magnification) and severe sliding wear (200x magnification) respectively. Fine cutting wear, severe wear and rolling-element bearing fatigue spherical was also observed in mileage 20000 km. The high ratio of large-to-small particles is indicative of stress levels far above that which the surface can tolerate.

Figure 5(a), (b) and (c), normal rubbing wear, particles typical of the break-in period and cutting wear were presents in mileage 40000 km. These particles were found in oil sample of mileage 20000 km. In addition, rolling-element fatigue and severe sliding wear were also found in mileage 30000 km nevertheless the colour of severe sliding wear in mileage 40000 km shows results causes by surface heating with a high speed.
As can be observed from Figure 6, wear morphology in mileage 50000 km for normal rubbing wear, break-in period, cutting wear and gear fatigue were also present in mileage 30000 km and 40000 km.

From the observations in this study, existence of wear particles from normal rubbing, break-in period, cutting, scuffing, severe sliding, rolling-element fatigue and gear fatigue wear are found in used transmission fluid of CNG bus gearbox. Other than existence wear particles, corrosive, red oxides, black oxides, copper alloy wear etc were not found. Summary of all the results were presented in Table 1.

| Table 1. Wear particles profiles at various mileages |
|---------------------------------------------------|
| Types of Wear Particles | Mileage (km) |
|                        | 20K | 30K | 40K | 50K |
| Normal rubbing wear    | ✓   | ✓   | ✓   | ✓   |
| Break-in period        | ✓   | ✓   | ✓   | ✓   |
| Cutting wear           | ✓   | ✓   | ✓   | ✓   |
| Scuffing wear          | ✓   |       | ✓   | ✓   |
| Severe sliding wear    | ✓   | ✓   |       | ✓   |
| Rolling-element fatigue| ✓   | ✓   | ✓   |       |
| Gear fatigue wear      | ✓   |       | ✓   |       |
4. Interpretations of Observed Wear Morphology

From the microscopic evaluation summarised in Table 1, seven types of wear particles morphology were observed. It can be seen that, cutting wear and rolling-element fatigue wear were presents in most of the results for 20k, 30k, 40k and 50k millage.

Cutting wear occur due to the result of penetration surface one to another that generated a very thin wire and long large stripes with thickness of 0.25 micrometers (μm) particles. According to Sondhiya and Tiwari et.al [9,10], these particles is generated of off by two factors; misaligned of the hard component and soft surface that was cut off by hard sharp edge. It also suggested that, the component is approaching to fail if the quantities of the particles size increasing to 50 μm long.

Rolling-element fatigue wear is also known as a bearing wear particle. This wear particle is created by periodical contact of the bearing surface, hence generated a spherical fatigue element [12]. According to Vlcek et al. [14], there are a few factors that affected the rolling-element fatigue varying such as material, processing and manufacturing along with operating conditions.

Normal rubbing wear and break-in period were presents in mileage 20k, 40k and 50k while Severe sliding wear was found in mileage 20k, 30k and 40k. Rubbing wear particles generated were observed as a normal sliding wear in the engine and machine. Normally, the size of flat platelets generated as small as 5 microns and up to 15 microns [9,11]. For the break-in period is deal with the changes in engine usually during the early period where it is affected from the high friction, high blow-by or high oil consumption [15]. Meanwhile, the severe sliding wear particles can be identified by the parallel pattern on the surface as it occurred due to the high and low speed between the components. The particles size generally larger than 15 microns as it can up to 30 microns [9,12].

From Table 1, scuffing wear and gear fatigue wear were the least wear particles present in the mileages. Scuffing wear particles presents due to the surface contact between metals as it affected by a high speed or high load surfaces working rotation. This particle generated by a few causes such as excessive heat by friction, existence of solid welding and characteristics of materials contact [16, 17]. Meanwhile, as for the gear fatigue wear, it has a common wear characteristic with rolling-element bearing fatigue particles [10].

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References

[1] M. I. Khan, T. Yasmin, and A. Shakoor, “Technical overview of compressed natural gas (CNG) as a transportation fuel,” Renew. Sustain. Energy Rev., vol. 51, pp. 785–797, 2015.

[2] A. Thiruvengadam, M. Besch, V. Padmanaban, S. Pradhan, and B. Demirgok, “Natural gas vehicles in heavy-duty transportation-A review,” Energy Policy, vol. 122, no. July, pp. 253–259, 2018.

[3] BP Statistical Review of World Energy 2014, (http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy.html) [accessed on September 14, 2014].

[4] Shi, J., Li, T., Peng, S., Liu, Z., Zhang, H., Jiang, Q., 2015. Comparative Life Cycle Assessment of remanufactured liquefied natural gas and diesel engines in China. J. Clean. Prod. 101 https://doi.org/10.1016/j.jclepro.2015.03.080.
[5] Yoon, S., Hu, S., Kado, N.Y., Thiruvengadam, A., Collins, J.F., Gautam, M., Herner, J.D., Ayala, A., 2014. Chemical and toxicological properties of emissions from CNG transit buses equipped with three-way catalysts compared to lean-burn engines and oxidation catalyst technologies. Atmos. Environ. 83, 220e228. https://doi.org/10.1016/j.atmosenv.2013.11.003.

[6] O. Levi and N. Eliaz, "Failure analysis and condition monitoring of an open-loop oil system using ferrography," Tribology Letters, vol. 36, pp. 17-29, 2009.

[7] R. Bowen, D. Scott, W. Seifert, and V. Westcott, "Ferrography," Tribology International, vol. 9, pp. 109-115, 1976.

[8] W. Seifert and V. Westcott, "A method for the study of wear particles in lubricating oil," Wear, vol. 21, pp. 27-42, 1972.

[9] Om Prakash Sondhiya, Amit Kumar Gupta, "Wear Debris Analysis of Automotive Engine Lubricating Oil Using By Ferrography:, International Journal of Engineering and Innovative Technology (IJEIT), Volume 2, Issue 5, November 2012.

[10] Dr.Ashesh Tiwari and Satya Prakash Dubey, “Analysis Of Wear Rate Of Internal Combustion Engine Using Ferrography Technique”, International Research Journal of Engineering and Technology (IRJET), Volume: 04 Issue: 06, June -2017.

[11] M.C. Isaa, N.H.N. Yusoff, Hasril Nain, Mohd Subhi Din Yati, M.M. Muhammad, Irwan Mohd Nora,” Ferrographic analysis of wear particles of various machinery systems of a commercial marine ship”, The Malaysian International Tribology Conference 2013, MITC2013, Procedia Engineering 68 (2013) 345 – 351.

[12] Wei Hong, Wenjian Cai, Shaojing Wang, Mileta M. Tomovic, “Mechanical wear debris feature, detection, and diagnosis: A review”, Chinese Journal of Aeronautics, (2018), 31(5): 867–882.

[13] David E. Sander, Hannes Allmaier and Hans-Herwig Priebsch, “Friction and Wear in Automotive Journal Bearings Operating in Today’s Severe Conditions”, Advances in Tribology (Chapter 7), 2016.

[14] Brian L. Vlcek and Erwin V. Zaretsky, “Rolling-Element Fatigue Testing and Data Analysis - A Tutorial”, Society of Tribologists and Lubrication Engineers (STLE), 54: 523-541, 2011.

[15] G. C. Barber and K. C. Ludema, “The Break-In Stage of Cylinder-Ring Wear: A Correlation Between Fired Enginges and A Laboratory Simulator”, Elsevier Sequoia, Wear, 118 (1987) 57-75.

[16] Remigiusz Michalczewski, Marek Kalbarczyk, Michal Michalak, Witold Piekoszewski, Marian Szczerk, Waldemar Tuszyński and Jan Wulczynski, “New Scuffing Test Methods for the Determination of the Scuffing Resistance of Coated Gears”, Tribology-Fundamentals and Advancements, Chapter 6.

[17] Remigiusz Michalczewski, Witold Piekoszewski, Waldemar Tuszyński, Marian Szczerk and Jan Wulczynski, “The New Methods for Scuffing and Pitting Investigation of Coated Materials for Heavy Loaded, Lubricated Elements”, Tribology - Lubricants and Lubrication, October 2011.