Conductivity Analysis of Lubricant in Terms of Deterioration by Using a Hall Effect Sensor

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***Abstract*—This paper investigates the efficiency of lubricant analysis by using electrical conductor theory that applied to check the performance of the lubricant, it will be indicate a life cycle of lubricant. The measurement process has led Electrochemical cell, Induction coil and Hall Effect sensor for electrochemical field analysis and compare it with electrical conductivity. In conductivity measurement experiment, we consider dynamic measurement velocity at 80 RPM with a lubricant Semi-Synthetic 10W-40 type by 5 different life cycle samples ratio, Used lubricant : Unused lubricant are 100% (4: 0), 75% (3:1), 50% (2:2), 25% (1:3) and 0% (0:4). The voltage output of Hall Effect sensor of 100% sample measurement at 100 degree Celsius is higher than the voltage output of 75%, 50%, 25% and 0% sample are 7.04%, 12.21%, 21.25% and 28.65%, respectively. The average percentage of Hall Effect sensor errors with the dynamic measurement method of the 5 lubricant samples was 2.87. Even though this measurement method had a high percentage of errors, but it has a cost advantage over the current measuring devices such as the Viscometer which is expensive cost.**

***Index Terms*—conductivity, hall effect sensor, induction coil, lubricant, measurement**

I. Introduction

In various industries, lubricant is very important because it helps to maintain the lubricant for maximum performance. The lubricant has a variety of standards such as Society of Automotive Engineers (SAE), American Petroleum Institute (API) etc. Current, there are many methods to check the quality of lubricant. For example, the Ultrasonic Measurement [1], Photoacoustic Measurement [2] and Magnetic Viscosity [3] In this article, we have designed the electrical conductivity measurement of the lubricant based on electrode investigate principle [4], are divided into 2 experiments which are Static and Dynamic [4, 5] experiment. The electrical conductivity measurements of different 5 life cycle types of Semi-Synthetic 10W-40 lubricant and the temperature study that affect to the electrical conductivity of the lubricant. For performance analysis of the lubricant has applied Hall Effect sensors for electromagnetic field measurements to compare with the electrical conductivity of the lubricant. The Objectives of this research are reduce the cost of investigation, simplify the usage and make the tools has efficiency same as standard tools.

II. Fundamental Method

A. Conductivity Measurement

Electrical conductivity measurement method depends on the cross section of the electrode (A), the distance between the two poles (L) and the current (I) flowing through the liquid. Which is the voltage (V) and the resistance in the liquid (R_c) determine the flow of current from the positive to the negative poles as shown in (1) and Fig. 1 [5].

$$\sigma = \frac{L}{(R_C)A} = \left(\frac{I}{V}\right)\frac{L}{A} \tag{1}$$

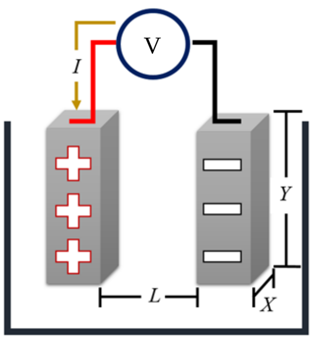

Figure 1. Electrochemical cell.

B. Hall Effect Sensor

In this research, the Hall Effect sensor number A1301 is used to measure electromagnetic fields generated by induction coils. The Hall Effect sensor is used for converting the electromagnetic field into the voltage shown in (2) [6].

$$V_H = \frac{R_H}{W_H} I_H B_H \tag{2}$$

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Where V_H is Hall voltage (V)
B_H is magnetic Flux density (tesla)
W_H is the thickness of Hall generator (mm)
R_H is Hall coefficient (Ω)
I_H is the constant current (mA)

C. *Generate of Magnetic Field*

Fig. 2 shows the relevant variables for induction coil design, namely, The electromagnetic field (B) and The inductance (L_s), which correspond to (3) and (4) [7].

$$B = \frac{\mu NI}{l} \tag{3}$$

$$L_s = \frac{\mu N^2 \pi R^2}{4l} \tag{4}$$

Where μ is material permeability (H/m)
N is number of turns in wire coil
l is coil length (m)
R is radius of coil (m)
I is current flowing to through the coil (A)

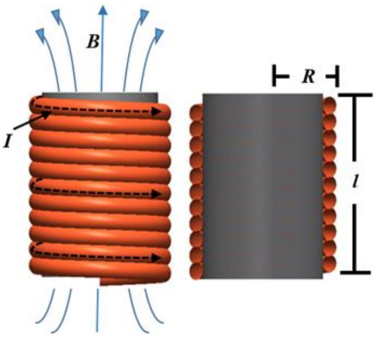

Figure 2. Cross sectional of coil.

Fig. 3 describes the induction coil design which used in the experiment. In this experiment, standard SWG No. 22 copper wire 0.700 mm diameter and the ferrite core were used for 10 mm diameter and 25 mm length. 100 round copper wire coils wrap effect to an inductance of 1.1542 mH and a resistance of 0.48602 Ohm. The Hall Effect sensor is installed at the center of the top of the induction coil.

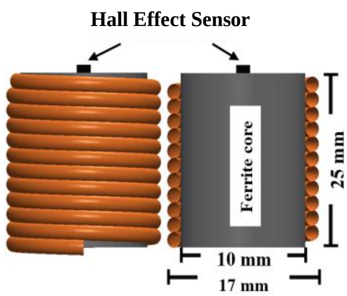

Figure 3. Simulated cross-section of induction coil.

III. Measuring System

This research uses a 15 volts power supply as a source of electrical conductivity with stainless steel plates No.304 are used for two electrodes with a width of 20 mm, length of 40 mm and thickness of 1 mm. The distance between two plates is 1 mm by immersing the stainless sheet into the lubricant with a depth of 20 mm. Current amplifier circuits are used for power amplification and transmitted to the induction coil for be the source of the electromagnetic field. The induced magnetic field is converted by the Hall Effect sensor into electrical voltage. The 10-bit microcontroller is responsible for processing the electrical voltage from the Hall Effect sensor and sent to the computer for recording. As shown in Fig. 4.

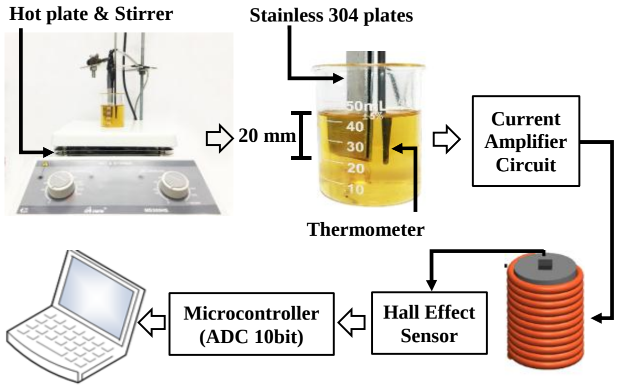

Figure 4. Block diagram and measurement system.

IV. Experiment Condition of Lubricant

In this section, the Hall Effect sensor is used to measure the electrical conductivity of the lubricant Semi-Synthetic 10W-40 type with old 10,000 km used and new lubricant by mixed to 5 different ratios with the total volume of 40 ml, as shown in Table I. And the lubricant sample shown in Fig. 5, by using a dynamic method at 25 to 100 degree Celsius, total measurement 10 times and average storage 5 times/sec.

TABLE I. Indicates the Mixing Ratio between the Lost Performance Lubricant and the New Lubricant Which Is Not Used. There Are 5 Different Types.

Samples (Ratio)	Old lubricant (mL) (10,000 km)	New lubricant (mL) (0 km)
100% (4:0)	40	0
75% (3:1)	30	10
50% (2:2)	20	20
25% (1:3)	10	30
0% (0:4)	0	40

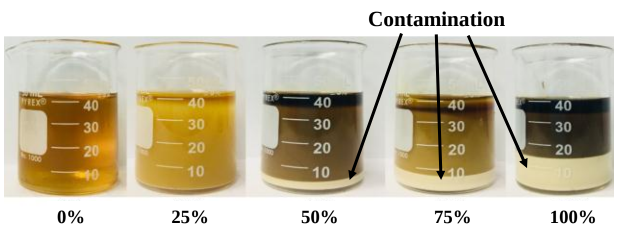

Figure 5. The different samples of the five lubricant.

V. Experiment and Analysis

The experiment was divided into 3 parts as follows.

A. Static and Dynamic Methods at Room Temperature

This experiment was conducted by comparing the electrical conductivity of all three types of the lubricant are Full Synthetic, Semi-Synthetic and Synthetic by static and the dynamic method with velocity of 80 RPM at room temperature of 25 degree Celsius, 10 times and average storage 5 times/sec.

Fig. 6 shows the results of the electrical conductivity of the three types of the lubricant indicating that the three lubricants have similar electrical conductivity. The dynamic method has better conductivity than the static method due to the dynamic measurement uses a distillation technique that results in electrons moving better than the static measurements.

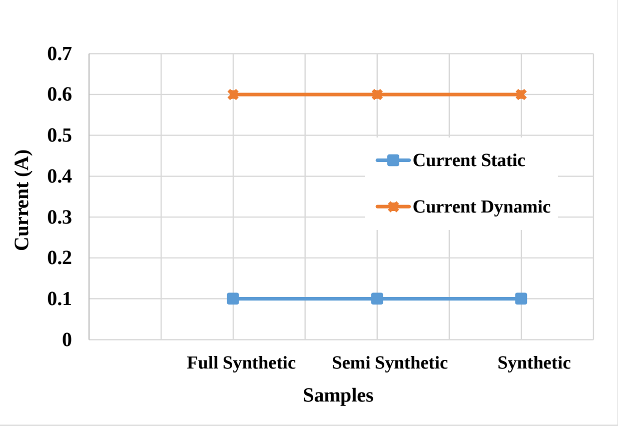

Figure 6. The current flowing through coil.

Fig. 7 shows the output voltage of the Hall Effect Sensor for measuring the voltage of the three types of the lubricant. We found that the three samples have similar voltages. And the dynamic measurement method has a voltage higher than the static measurement method. Due to the dynamic measurement has high conductivity that results in high voltage of Hall Effect Sensor.

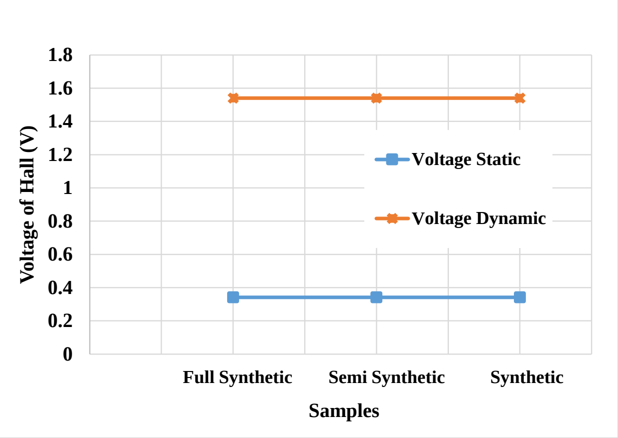

Figure 7. The Voltage of Hall Effect Sensor

B. Static and Dynamic Methods with Temperature

This experiment was conducted by comparing the electrical conductivity of all three types of the lubricant are Full Synthetic, Semi-Synthetic and Synthetic by static and the dynamic method with velocity of 80 RPM at temperature of 25 to 100 degree Celsius, 10 times and average storage 5 times/sec.

Fig. 8 shows the electrical conductivity of all three types of lubricant. We found that when the temperature increased, it is effected to better electrical conductivity of the three types of lubricant from both measurement method. Due to the temperature increased, then it made the viscosity of the lubricant decreases and effected to better electrical conductivity. The experiment results show that the dynamic measurement method is more effective in conducting electricity than static measurement method, but the different types of oil did not effect on conductivity.

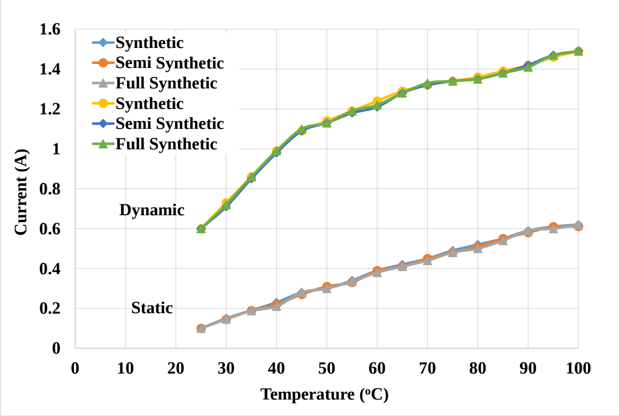

Figure 8. The current flowing through coil with temperature.

Fig. 9 shows the effect of the electrical conductivity of all three types of the lubricant. We found when the temperature increased, the voltage of the three types of the lubricant have improved. When the temperature increased, the viscosity of the lubricant will decrease. It's resulting in better voltage. Based on the results, we found that the dynamic measurement method has a higher voltage than the static measurement method.

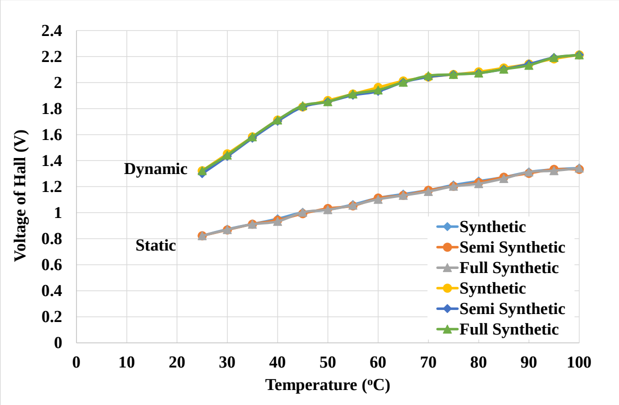

Figure 9. The Voltage of Hall Effect Sensor

C. Dynamic with Temperature

This section applies the Hall Effect sensor for the electrical conductivity measurement of the lubricating oil sample by used dynamic method at a speed of 80 RPM, temperature 25 to 100 degree Celsius with a total 10 times measurements and an average of storage 5 times/sec.

Fig. 10 shows the electrical power of the five samples. We found when the temperature increased, its result in the higher conductivity of the five samples and tend to go in the same direction. The 100% sample had the highest conductivity and the 0% sample had the lowest conductivity. As a result of 100% of the sample's dirtiness is greater than the 0% sample, resulting in a 100% sample had better conductivity than the 0% sample. It's not suitable for use.

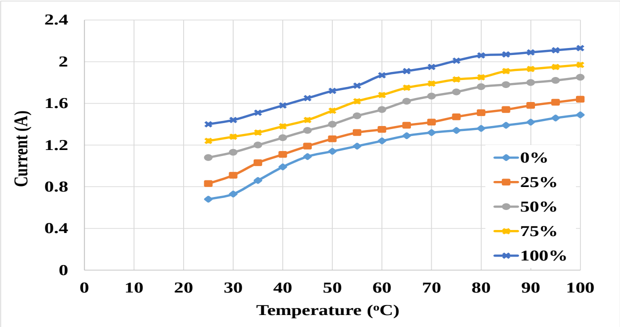

Figure 10. The current flowing through coil

Fig. 11 shows output voltages of Hall Effect sensor for electrical conductivity measurements of five samples. We found that when the temperature increased, it is effected to the Hall Effect sensor voltage value of all five samples are increased too. The 100% sample will have the highest voltage value and 0% sample have the lowest voltage due to dirtiness of 100% sample is greater than 0% sample. It is effected to 100% sample had the electrical conductivity better than 0% sample. The effect of excessive electrical conductivity on the lubricant is not suitable for use

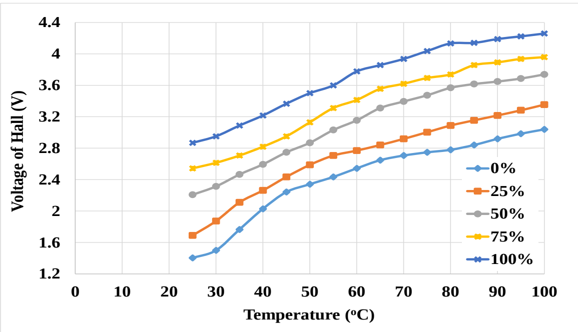

Figure 11. The voltage of hall effect sensor

VI. Summary

In this experiment, we study the electrical conductivity of the lubricant by electrode measurement method by applied the Hall Effect sensor. It was found that the electrical conductivity of the long-time used oil is higher than the short time used oil respectively. The static and dynamic measurements show that the dynamic measurements provided the better electrical conductivity than Static measurement due to dynamic measurements help to increase the distribution of electrons in the lubricant. At higher temperatures, it is provided the higher electrical conductivity too. Due to this higher temperature, the lubricant has less viscosity. This is also effected in a better performance of the stainless steel sheets which is measurement device has the better electrical conductivity.

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