Hall Effect Sensor for Measuring Metal Particles in Lubricant

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***Abstract*—This paper presents the development of hall effect sensor for measuring the contamination of lubricant in industry. This technique is based on the principle of the magnetic field and Hall Effect. The magnetic field is made up of a permanent magnet which is measured by a Hall Effect sensor. The measured magnetic field can be estimated the level of contaminants in the oil by the ferrous particles which indicate a lifetime of lubricant. Therefore, this issue is taken into account to identify the suitable time for draining (refer to NAS1638 standard). The experimental results were performed to demonstrate the output voltage of the Hall Effect sensor relating to the level of the metal particles in the lubricant. Our instrument is low cost and it can be applied in the factory, machinery, automobile, oil industry as well.**

***Index Terms*—Hall effect sensor, magnetic measurement, lubricant quality measurement**

I. INTRODUCTION

THE Lubricant degradation is a major cause of damage in machinery such as engine, pump, compressor and transmission system etc. The use of degenerated lubricant has been one of cause making the machine damage [1]. The metal particles which is mainly contamination of scrap metal parts due to wear and tear of machinery. The time of oil change for the machines based on the quality and lifespan. There are many papers studying about the relation between the quality of lubricant after using and the failure of machines. B. W. Wilson and G. Silvernail [2] designed the automated in-line machine fluid analysis for marine diesel and gas turbine engines and Ren Guojun et.al [3] created an. on-line monitoring technique for contamination degree of diesel engine lubricating oil in order to reduce the damage in engines. The monitoring system for contamination degree has been developed to define the suitable time for changing the oil that there were many papers presented the principle of capacitive sensor, infrared absorption and optical fiber sensing were applied to define the degree of contamination [4-6]. This paper presents the new technique using Hall Effect sensor to measure the metal in lubricant. The principle of measuring the magnetic field has been applied to detect the level of contamination in engine oil, scrap metal, according to the NAS1638 standard.

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II. MATERIAL AND METHOD

Magnetic field (B) can be calculated by Lorentz force (F) depending on electron or the magnitude of the charge (q) and angular position (θ) as illustrated in equation (1) [7] :

$$F = qvB\cos\theta \quad (1)$$

Where

F is Lorentz force,
q is the magnitude of the charge ,
v is the velocity of the charge
B is magnetic field

Hall generator is made up of semiconductor type P and type N. Hall voltage is generated by magnetic field as shown in equation 2 and 3 [7]:

$$V_H = IB / qpd \quad (2)$$

And

$$V_H = IB / qnd \quad (3)$$

Where

V_H is voltage of hall effect sensor (Volt)
I is the current flow through hall generator (amperes)
B is the density of magnetic field (Tesla)
d is the thickness of hall generator (m.)
p is the number of holes.
n is the number of electrons.

Contamination of the oil may cause by inside and outside of the machine such as wear and tear of the machinery or the contamination from in-let air in opened system , so the wear particles are both non-ferrous and ferrous metal or either , all of them affect to the performance of the machine and including system shut down and damage. Figure 1. show most of the particles size which have most effect should be between 1-40 μm. but the particles size have less than 1 μm. has not impact of wear and tear in machinery's damaged. In this paper presents the detection of contaminants such as ferrous metal which has a significant

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impact on the change of the magnetic field, depending on quantity of metal contamination in the oil. Figure 2. shows the overall structure of the measurement system based on the principle of a magnetic field. The permanent magnet generates a magnetic field (*B*), which can be effect to metal contaminants in the lubricant that is cause of the magnetic field changed according to the weight of the contaminants. The Hall sensor can detect changing of magnetic field and generate the voltage output to the 12 bit- Analog to Digital convertor for sending data to the data acquisition based on microcontroller then it passes data to store on the computer and data analysis.

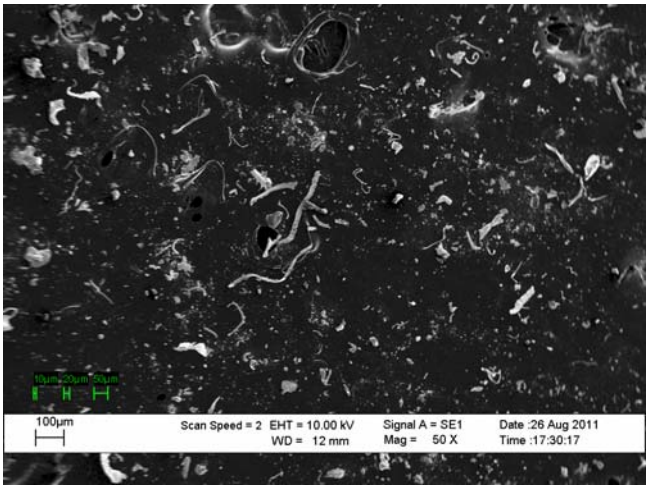

Fig. 1 The particle size of metal by SEM.

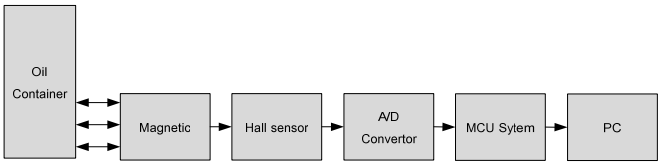

Fig. 2 The schematic diagram of Hall Effect sensor system.

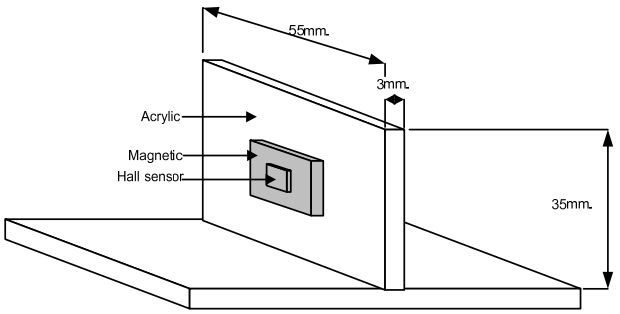

Fig. 3 Experiment apparatus of measurement system.

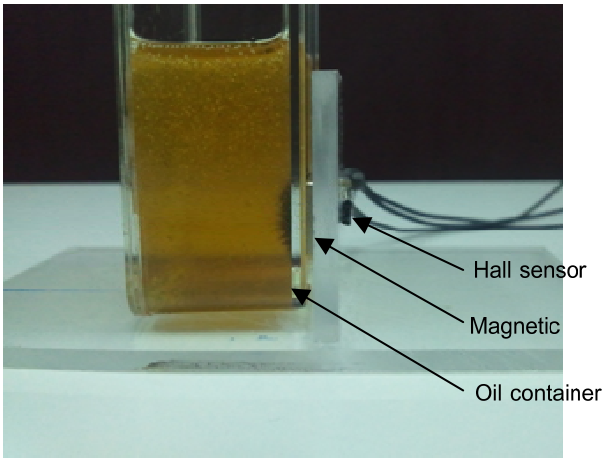

Fig. 4 Hall Effect sensor installation

The structure of the measurement system has shown in Figure 3. Measurement system consists of a permanent magnet for generating a magnetic field (magnetic field, *B*) to the sample in the oil container and Hall sensor for detecting the magnetic field. The permanent magnet size is 2 mm. of thickness, 12 mm. of width and 15 mm. of length. The hall sensor is mounted into the center of permanent magnet on another side of the acrylic plate. The gap between hall sensor and permanent magnet is 3 mm. in order to protect the saturated output voltage of hall sensor in case of the magnetic field over the range. Figure 4 is illustrated the sensor and sample installation.

III. Experiment Results

The measurement of metal contamination under NAS1638 standard which uses the particle counter method in determine of contamination degree. The contamination degree was divided 14 levels from NAS00 to NAS 12 by increase in the ratio of each level would be 2 times and converted from particle counter to be the gravimetric method. According to above mention, we are able to determine the level of contamination degree in the higher than 12 levels by using extrapolation method that was used in this paper as shown in table 1[6].

In this paper presents a measure of hydraulics oil grade ISO VG100 which is widely used in industry, such as gears box, pump and compressors etc. as Figure 5 shows the different level of contamination that the result of testing is referred to the contamination of the metal when it exceeds the highest of L-CKC industrial closed gear oil standard as shown in table 2. The maximum value for an oil change was performed at 0.5% of Mechanical impurities which should be comparable with standard NAS1638 in contamination level at NAS18[6]. Therefore Hall Effect sensor was calibrated for achieving properties and performance of measurement system by using weight of the contaminants since NAS 12 to until weight of the contaminants in the oil at 1 gram.

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Table 1. Weight contamination standard NAS1638.

Contamination degree	**12**	**13**	**14**	**15**	**16**
mg/25ml.	1.25	2.5	5	10	20
Contamination degree	**17**	**18**	**19**	**20**	**21**
mg/25ml.	40	80	160	320	640

Table 2. L-CKC exchanging standard of industrial closed gear oil (method :SH/T0586)

Item	**Exchanging oil Standard**
appearance	abnormity
Movement viscosity(40°)rate of change/ % >	+15 or -20
moisture / %	0.5
Mechanical impurities /% ≥	0.5
Copper corrosion(100 C , 3h/degree ≥	3b
Timken OK value /N ≤	133.4

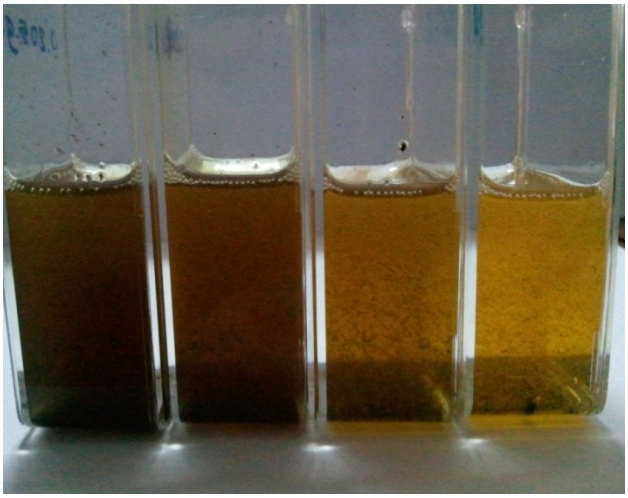

Fig. 5 The prepared sample.

Table 3. Output voltage of the Hall sensor.

Weight(mg)	**1**	**2**	**5**	**10**	**20**	**40**
Voltage (V)	3.737	3.737	3.737	3.739	3.741	3.745
Weight(mg)	**80**	**100**	**200**	**300**	**400**	**500**
Voltage (V)	3.752	3.758	3.774	3.788	3.799	3.809
Weight(mg)	**600**	**700**	**800**	**900**	**1000**	
Voltage (V)	3.818	3.825	3.831	3.836	3.842	

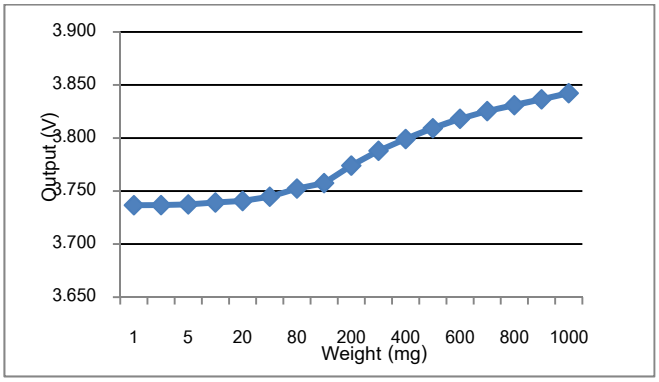

Fig.6 The output voltage of hall sensor corresponding to weigh level.

In table 3, the changing of output voltage of hall sensor is corresponds to the contamination level. In the range of the measurement of contamination, the level of 10 mg. can be classified as the NAS15, which is equivalent to the level that indicates the suitable time for changing the lubricant oil according to the prescribed standards. This system is able to detect the level of contamination at higher than level of NAS14. The hall sensor cannot response the low level signal of magnetic because of low the sensitivity. Therefore, it cannot determine the contaminant level at lower than 10 mg.

Due to the sensitivity of the hall sensor is used to respond to the changing magnetic field. The value of this test will measure a total of 10 times the weight of level in order to find the repetition of the measurement. (Repeatability) of the errors that occurred with the highest value at the (error) + / - 1mV.

It was mentioned that the test is the only lubricant of grade ISO VG 100. The sensors are more reliable and can be measured with various grades of oil . It does not depend on the viscosity (viscosity), turbidity and the composition of the oil itself. Oil has been tested with a second example of Figure 7 shows the test unit with the oil viscosity as well as standard SAE grades 15W-40 and 20W-50 oil which is used in motor vehicles. Types of diesel and gasoline can be seen that the hall sensor can measure the change in the amount of contamination does not depend on the type of oil or viscosity. It will change only the amount of contamination of the metal.

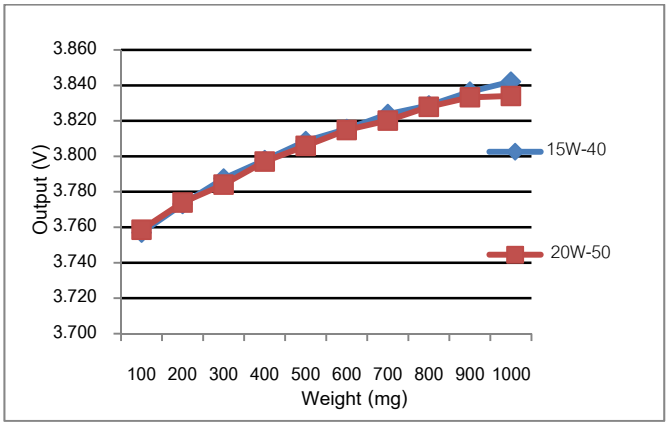

Fig. 7 Effect of standard tests measuring motor oil SAE grade 15W-40 and 20W-50.

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IV. Conclusion

The sensor has been developed for the measurement of contamination of the oil that was already mentioned in this article. The principle of the magnetic field is measured using a Hall Effect sensor, which has been created. It can be used to measure the amount of contamination of the metal (ferrous) in the oil. The reference standard for detecting oil is NAS1638. The results showed that the sensor can measure the amount of contamination of the metal, which is associated with change in the magnetic field in the oil .This system can measure contamination level since NAS 15, which can define the wear and tear of machinery, sufficient to indicate drain properly. The advantages of using the principles of measuring magnetic fields are able to reduce errors due to the turbidity of the oil due to each brand and grade the clarity and intensity of color as well, which need to be careful when using the optical measurement. Measurement system can be improved in terms of sensitivity and ability of measuring the contamination at a lower level, NAS15 by selecting the sensor that have high sensitivity to measure magnetic fields. Moreover, It can be updated to install on the machine that can measure in real time to prevent the damage of machinery.

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