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An Alarm System For Detecting Moisture Content In Vehicle Brake Fluid With Temperature Compensation

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Abstract - *Brake fluid is composed of polyethylene glycol, which has water and absorbs water in the air. When the moisture content of brake fluid is high, the boiling point decreases. This causes the brake fluid to vaporize because of the brake's high temperature, and the vapor lock is generated, which leads to the decrease or even failure of brake capacity. In this study, an alarm system that can measure brake fluid resistance and temperature is constructed to obtain the moisture content. This study is divided into two stages. In the first stage, different water content (0%, 1%, 2%, 3%, 4%, 5%) and different temperature (from 26 °C to 60 °C) of brake fluid were measured. The brake fluid's electrical resistance value is calculated, and the relationship between voltage and resistance is adjusted. Then the warning limit value of brake fluid water content is determined. In the second stage, the alarm system is established using the Arduino UNO board. When the sensor detects that brake fluid's moisture content exceeds the safety range, it will send a warning message to warn the driver.*

Keywords — *brake fluid, polyethylene glycol, moisture content, vapor lock, an alarm system.*

I. INTRODUCTION

The liquid brake system [1] is the most mainstream today, based on Pascal's Principle [2]. It uses the medium of brake fluid to generate the brake from the pedal to the brake actuator, so brake fluid plays an important role in the brake system. The services of the original factory to check the brake fluid are all waiting for mileage. It is only after the entrance maintenance test that it is decided whether to change it or not. However, before the mileage arrives, it is also possible to deteriorate [3]. In particular, the degree of change is relatively high. Brake fluid is not designed in a vacuum manner so that moisture will enter the brake fluid.

If the status of brake fluid is not detected immediately, it is dangerous. In 2017, there was more than 10 news about brake failure in Taiwan, which was due to the decrease of boiling point caused by the deterioration of brake fluid, the vaporization of brake fluid due to high temperature in the process of brake [4], and the loss of action force of brake [5, 6, 7]. In this study, the perceptual devices installed on the brake fluid kettle were developed under the consideration of safety to understand the brake fluid status immediately. When the brake fluid moisture content exceeded the set value, a warning signal was issued to warn people and protect people and passengers' safety. In the relevant literature review of brake fluid, Li Xuren et al. [3] presented the research and Development of brake system moisture content alarm equipment. They used brake fluid moisture content and resistance values to set up an alarm system. Warning signals are sent to the instrument panel to alert the driver when the brake fluid moisture content is too high.

II. THEORY

Tinghui Shi et al. [4] discussed the process of using ANSYS Fluent to calculate CFD, using Brake Pro CarSim to track the temperature curve of the plane road and the temperature of model downhill, and using ABAQUS to predict the temperature of brake fluid, including examples to further state that the process and results are compared to the number of tests. Gao et al. [5] used the moisture content, the resistance of brake fluid to establish a system of boiling points in the water sign of brake fluid and display the number as moisture content and automatic early warning system. In a study on the aging of vehicle brake fluid based on ethylene glycol [6], the fluid brake experiment in 38 small passenger cars found that the measured quantity's boiling point could be better represented as the quality of brake fluid more accurately than moisture content. The parameters of brake fluid can be monitored and controlled at the appropriate time to ensure whether the operation of the brake system is normal or not.

John E. Hunter et al. [7] divided the research project into two stages. In the first stage, the boiling point number is established in the selected train database. The brake fluid boiling points related to the manufacturer, type number, year, mileage, and service type are recorded. The second stage is the test of three different types of cars. The three types of cars are trucks, public service, and small passenger cars. The moisture content used in the study was 5%, 3%, and 0% of the mixture. He Xinyi et al. [9] studied the effect of operating mode on the decline of brake efficiency. By means of the test method of brake decline in various countries, the effect of brake temperature increase on brake efficiency was tested by two different cars. It can be found from the papers when they experimented, they only took the boiling point of the brake fluid and did not take the temperature into account. The effect of the temperature on the resistance value was also very large. Therefore the temperature effect should be taken into account.

In the process of the brake, high temperature will lead to brake fluid boiling. Suppose the quality of brake fluid is poor, or the moisture content is caused by long-term use. In that case, it is easy for the brake to cause brake fluid vaporization to produce vapor lock due to high temperature, which leads to the decline or even failure of brake capacity. Although there are already various kinds of brake fluid inspection devices on the market, some are easy and cheap, but not standard, and the more advanced devices are unable to let the general public get started at a price. Therefore, in this study, we develop a warning system installed on the dashboard and can monitor the brake fluid at the same time. The materials used are the more common parts on the market to reduce the cost of the product, which does not affect the brake function of the car and easy to install and maintain.

III. EXPERIMENT AND RESULTS

This experiment is divided into three stages. The first stage is to measure the variation of temperature and resistance of brake fluid moisture content. The data measured from the experiment were then taken to derive the equation using the function polyfit( ) in Matlab. The experiment types of equipment used in the study are shown in Table 1. The second stage is to use the Arduino Uno board to establish a brake fluid alarm system using the first-stage equation. Then the brake fluid of different moisture content is measured to see if the system is working properly.

Three different brands of brake fluids are selected for the experiment. i.e., V, M, and C brands, respectively. Use the tube to adjust the capacity of different brake fluid, as shown in Fig. 1. Table 2 shows the oil and water capacity adjusted by different moisture content. Before setting the temperature measurement range, the brake fluid temperature of the actual car after 30 minutes of operation was measured. The highest temperature value was obtained when the range of practical temperature setting is set, and the measurement value is shown in Fig. 2. After the measurement, it is found that the brake fluid temperature can reach 52 °C, so the range of the temperature measurement was set from 26 °C to 60 °C. Moisture content is based on the general range of 0% to 5%.

A heating plate was used to heat the brake fluid, and the temperature interval is every two degrees. The configuration of the experiment is shown in Fig. 3. After recording the partial voltage value (Vout) of every two degrees, the (Rx) calculation formula, resistance value, of the brake fluid is calculated using the following formula.

$$V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2} \qquad (1)$$

$$R_1 = \frac{R_2 \times (V_{in} - V_{out})}{V_{out}} \qquad (2)$$

In the above formula, Vout is the partial voltage value, Vin is 12 V supplied by the power supply, R2 is the fixed resistance, and R1 is the brake fluid resistance.

The experimental steps can be expressed as follows:

1. The moisture content of the brake fluid is 0%-5%. They are used in the experiments.
2. The brake fluid is heated from 26°C to 60°C.
3. Temperature and voltage values are recorded every 2°C.
4. Calculate the partial voltage value.
5. The XY curve diagram is formed by using the electrical resistance value and the temperature.
6. The curve is transformed into an equation by MATLAB.

The first stage of the experiment is completed after completing the three brands of the brake fluid. After completing the first stage, the second stage is mainly to use the Arduino Uno board to calculate the brake fluid moisture content for the warning system with temperature compensation. The warning system is divided into three parts.

After adjusting the different moisture content of brake fluid, the temperature range is set to record the value from temperature 26 degrees to 60 degrees, and then convert it into the resistance value. After the resistance and temperature values are formed into a graph, the curve diagram is used to convert the partial voltage value into an equation. The curve relationship between the temperature and partial voltage value of three different brake fluid types can be shown in Figs 4, 5, and 6. It can be seen from the figures that the partial voltage value of different brand brake fluid increases with the increase of temperature. Still, the magnitude of partial voltage value and the degree of variation with temperature will change differently. With the temperature and partial voltage values, we can substitute the partial voltage values into Eq. (2) and obtain the resistance values shown in Figs. 7, 8, and 9. The Matlab function ployfit() is used to fit the curve of temperature and resistance. Assuming x is temperature and y is electrical resistance, the curve equations of temperature and resistance of different brake fluid can be obtained. The converted equation diagrams are shown in Figs. 10, 11, and 12.

0% moisture content

$$y = 0.001003864605 \times x^3 - 0.020062634556 \times x^2 - 18.272092141456 \times x + 3097.699293406909 \qquad (3)$$

1%moisture content

$$y = -0.0023100305297 \times x^3 + 0.4028193979737 \times x^2 - 25.5673029954913 \times x + 811.4340870292701 \qquad (4)$$

2%moisture content

$$y = 0.001751977408436 \times x^3 - 0.228363348735364 \times x^2 + 7.917759380038679 \times x + 55.666850400144085 \quad (5)$$

3%moisture content

$$y = -0.0018166474944 \times x^3 + 0.2565319529358 \times x^2 - 12.2483239898097 \times x + 236.6819900526531 \quad (6)$$

4%moisture content

$$y = 0.000670048483114 \times x^3 - 0.100048405991451 \times x^2 + 3.859323568835910 \times x + 28.054184223539899 \quad (7)$$

5%moisture content

$$y = 0.001855004108768 \times x^3 - 0.255146325789815 \times x^2 + 10.341009306940302 \times x - 68.029943828699743 \quad (8)$$

From the above figures, we can see that the converted curve is very close to the original curve. We can use the temperature-resistance curve equation to write it to the development board to complete the brake fluid moisture content warning system. Fig. 13 shows a photo of the experiment process. After the brake fluid moisture content warning system has been built on the Arduino Uno board, the brake fluid is again adjusted to use the warning system statistical measurement. The system will automatically measure the partial voltage value and convert it into the resistance value by itself.

From the above comparison diagram, we can see that manual measurement in the first stage is unstable, but we can still see the trend of different moisture content data. The second stage is to use the program to detect the data more accurately. Comparing the results obtained in the second stage with the first stage shows that the error is small and similar. Fig. 14 and Fig. 15 are the Arduino circuits for the second stage of the preliminary construction. In the third stage, the LED is tested for normal operation. Table 3 is the test results of the third stage experiment. From the table, we can see that the LED is on when the brake fluid's moisture content is above 3%. Therefore the alarm system is working properly.

IV. CONCLUSIONS

This study, this research aims to develop a brake fluid moisture content warning system with temperature compensation. In the experiment, the brake fluid's electrical resistance was varied with moisture content (0% ~5%) at different temperature values. Therefore, using the equation of 3% moisture content as a warning value is a very reasonable setting value. The results obtained in the experiment are as follows:

1. The brake fluid resistance value of any brand will decrease with the increase of moisture content. The resistance value of different moisture content will decrease with the increase of temperature.
2. The resistance value is consistent with the temperature trend. However, different brake fluid's electrical resistance value is still falling, so it is impossible to use only one equation for different kinds of brake fluid. (3.3)
3. When the alarm system is used to detect different brake fluid kinds, the equation within the program needs to be changed. (3.4)

From the experiment results, it can be seen that the moisture content alarm system can perform an effective operation.

(3.5)

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Table 1 Practical appliances used in the first phase of the experiment

Name	Model
Digital display DC dual power supply	HILA DP-30032
Volt-ohm-millimeter	DT-830B
Probe type thermometer	GE-T9A
Plate heater	DB-XAB
Self-made stainless steel probe.	Self-made
Self-made stainless steel container	Self-made

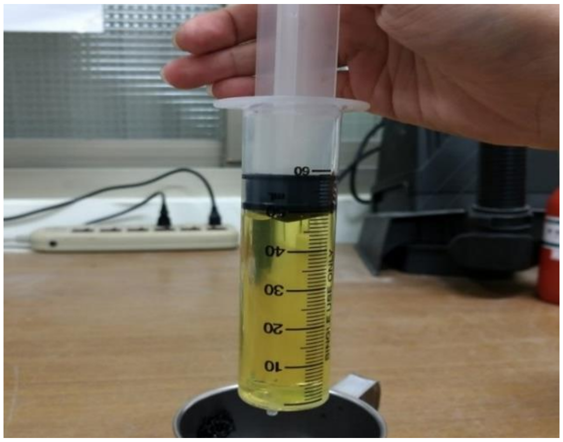

Fig. 1 Needle cartridge modulation

Table 2 Oil and water capacity of different moisture content

Moisture content	0%	1%	2%	3%	4%	5%
Brake fluid (ml)	100	99	98	97	96	95
Water (ml)	0	1	2	3	4	5

Fig. 2 Actual car test brake fluid temperature

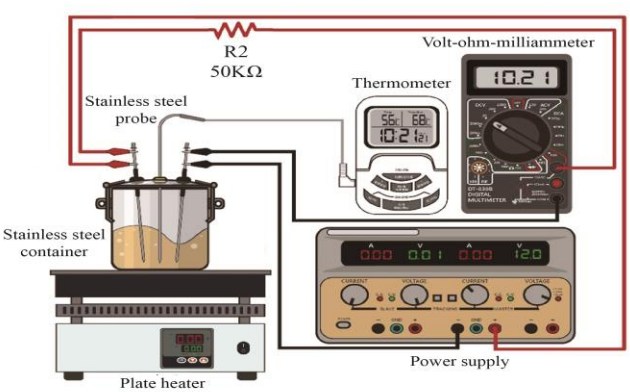

Fig. 3 The configuration of the experimental system

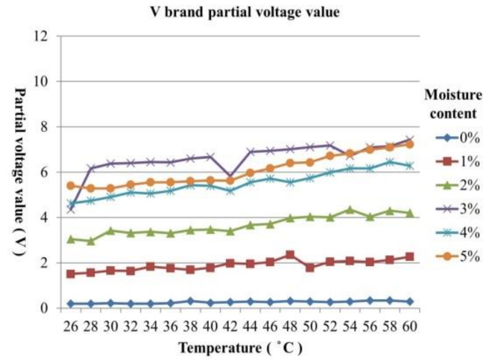

Fig. 4 Diagram of temperature - partial voltage value variation of V brand

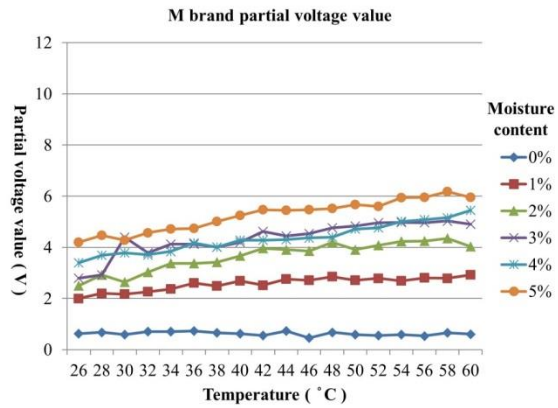

Fig. 5 Diagram of temperature - partial voltage value variation of M brand

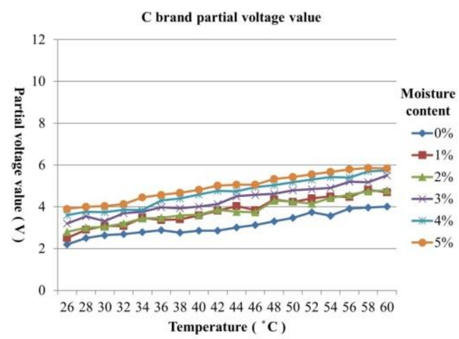

Fig. 6 Diagram of temperature - partial voltage value variation of C brand

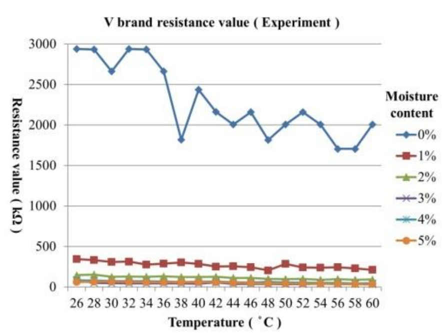

Fig. 7 Variation diagram of temperature - resistance value of V brand

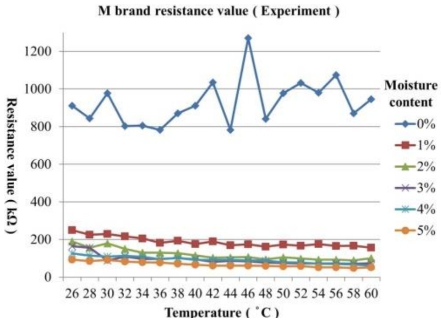

Fig. 8 Variation diagram of temperature - resistance value of M brand

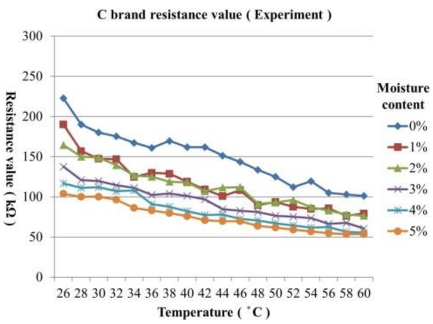

Fig. 9 Variation diagram of temperature - resistance value of C brand

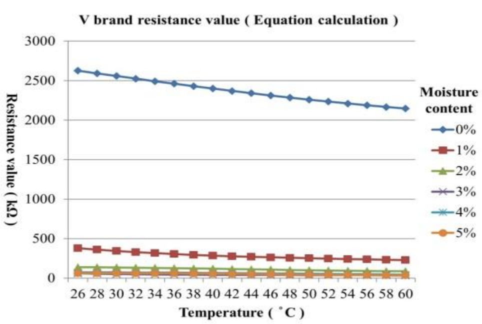

Fig. 10 Diagram of temperature - resistance value change of V brand (After conversion).

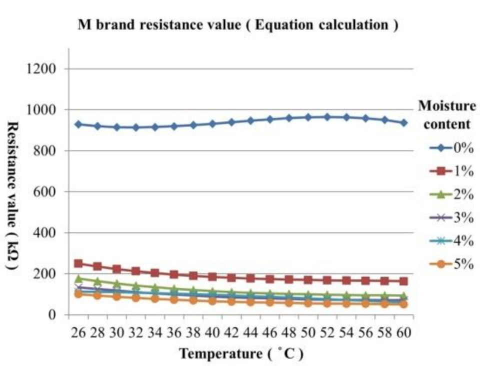

Fig. 11 Diagram of temperature - resistance value change of M brand (After conversion).

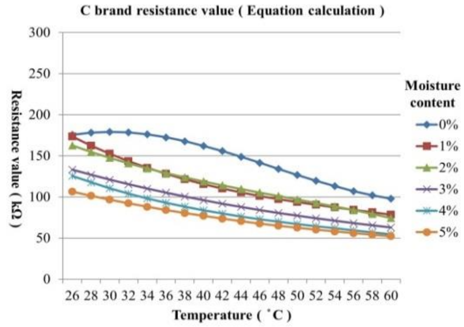

Fig. 12 curve diagram of temperature - resistance value change of C brand (After conversion).

Fig. 13 Photo of the experimental process

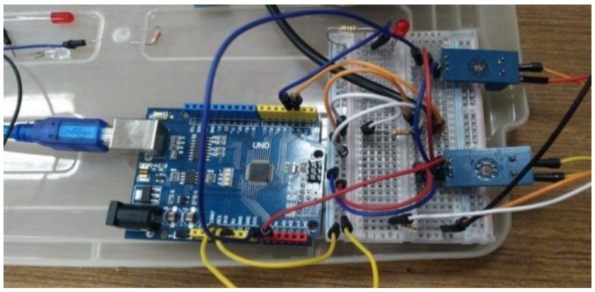

Fig. 14 The second stage of the preliminary construction of Arduino circuit – 1

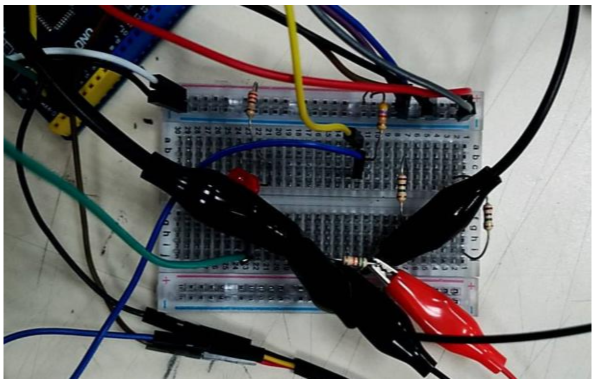

Fig. 15 The second stage of the preliminary construction of the Arduino

Table 3 V brand brake fluid test results

V brand					
Moisture content (%)	Temperature measurement value (°C)	(A) Calculation of resistance value by 3% equation conversion (kΩ)	(B) Measurement resistance value (kΩ)	A compared to B (< / = / >)	LED (on/off)
0%	26	100.62811	2495.496	A<B	off
	30	98.888489	2435.87	A<B	off
	40	88.599214	2279.032	A<B	off
	50	73.709913	2159.145	A<B	off
	60	59.078072	2136.273	A<B	off
1%	26	100.62811	281.8927	A<B	off
	30	98.888489	262.3234	A<B	off
	40	88.599214	220.9992	A<B	off
	50	73.709913	193.3488	A<B	off
	60	59.078072	182.8947	A<B	off
2%	26	100.62811	140.7514	A<B	off
	30	98.888489	125.1279	A<B	off
	40	88.599214	99.56571	A<B	off
	50	73.709913	85.99602	A<B	off
	60	59.078072	75.30865	A<B	off
3%	26	100.62811	99.497482	A>B	on
	30	98.888489	94.430984	A>B	on
	40	88.599214	86.956527	A>B	on
	50	73.709913	70.262092	A>B	on
	60	59.078072	57.495326	A>B	on
4%	26	100.62811	80.67031	A>B	on
	30	98.888489	75.7499	A>B	on
	40	88.599214	64.97932	A>B	on
	50	73.709913	55.53887	A>B	on
	60	59.078072	46.35824	A>B	on
5%	26	100.62811	59.99689	A>B	on
	30	98.888489	57.20281	A>B	on
	40	88.599214	49.61457	A>B	on
	50	73.709913	41.47206	A>B	on
	60	59.078072	33.1593078	A>B	on