**Development of a Coil-typed Oil Senor System for the Automobile Engine Oil on the Dielectric Constant**

Won-Tae Kim[1], Man-Yong Choi[2], Hae-Won Park[2], Jung-Hak Park[2]

**Abstract:** This paper is aimed to design the circuit of a coil-type oil sensor monitoring the deterioration in the driving condition and develops the device packaged to the automotive engine oil, which let a driver notify the optimized time for the exchange of engine oil. By applying the principle, which the deterioration of automotive engine oil can be expressed to the dielectric constant, the capacitance bridge circuit and the integrator circuit are designed and packaged to coil-typed engine oil. In this study, the range of operating temperature of engine oil is experimentally recommended within 55□ for the stability of a sensor designed. It is concluded that the characteristics of output voltage converted from the dielectric constant are linearly distribute

**Keywords:** Coil-typed Oil Sensor, Dielectric Constant, Capacitance Bridge Circuit, Integrator Circuit, and Automotive

## Introduction

Engine oil reduces the friction or abrasion of lubrication parts and provides cooling, pressure distribution and cleaning. While engine runs, low-temperature operation, incomplete combustion, engine abrasion and corrosion create water and acid. Piston movement generates metal debris, lowering oil viscosity. This shortens engine life. Over 70% of engine abrasion comes from direct friction between piston and cylinder within 30 seconds at the first start in the morning. Therefore, engine oil must be replaced periodically. Anti-Newton viscoelastic next generation premium class engine oil, replacement-free oil and oil additive have been recently commercialized. However, there have been insufficient studies on the proper interval for oil replacement.

Instrument panel mounted to a vehicle shows when it is necessary to refill fuel. However, engine oil replacement interval can be determined only through odometer. Moreover, it is impossible to determine the oil replacement interval without memorizing or recording previous mileage at which oil was replaced. Waste engine oil is used for fuel, road pavement or anti-corrosion of supports on construction sites. However, it is one of important pollutants in any case.[1]

Following methods for determination of oil replacement interval have been studied and used: 1) Oil replacement interval is warned or signaled by warning lamp or sound when driving mileage reaches at an oil replacement interval; 2) Measured oil viscosity is signaled to driver at a proper period through combination between acceleration sensor and revolution of engine oil fan; and 3) The color and viscosity of engine oil stuck to engine oil level gauge is determined by touching it. However, there have been no researches for determining oil replacement interval through direct oil measurement. In foreign countries, there have been many researches regarding engine oil measurement. Mills (1985) measured oil change by using magneto resistor sensor and measuring the change of flux path, caused by debris stuck to sensor head.[2] Masom (1985) installed a pair of inductive coils around an oil pipe installed separately and measured the changes in power output that are caused by the volume of debris in oil. Jantzen (1983) studied the optical measurement of debris in oil.[3] Kavlico and Park (1996) developed a sensor which converts the increase of dielectric constant caused by oil aging into DC output voltage.[4]

[1] Dept. of Bio-Mechanical Engineering, Kongju National University, 1 Daehae-ri, Yesan, Chungnam, 340-702, Korea

[2] Life Measurement Group, Korea Research Institute of Standards and Science, P.O. Box 402, Daejeon, 305-600, Korea

This study is aimed to develop an oil sensor that can measure the aging status of automobile engine oil so that drivers can determine the optimal interval for oil replacement, and analyzed the deterioration degree of engine oil by measuring dielectric constant.

## Analysis of Engine Oil

### The principle of measurement

In order to know if deterioration of engine oil can be determined by measurement of capacitance, this study used a liquid dielectric constant measurement device adopting the principle of cross capacitance measurement.[4] This study employed Thompson-Lampard theorem of electrostatics, and installed the measurement device in oil thermostat in order to maintain insulation between measurement poles and keep the temperature of measured liquid at a constant level.[5] Fig.1 is the diagram showing the measurement principle adopted by this study. This study uses the fact that any change in oil characteristics changes dielectric constant, and measures the changes in coil value (C) and Cref so that control is done by u-processor.

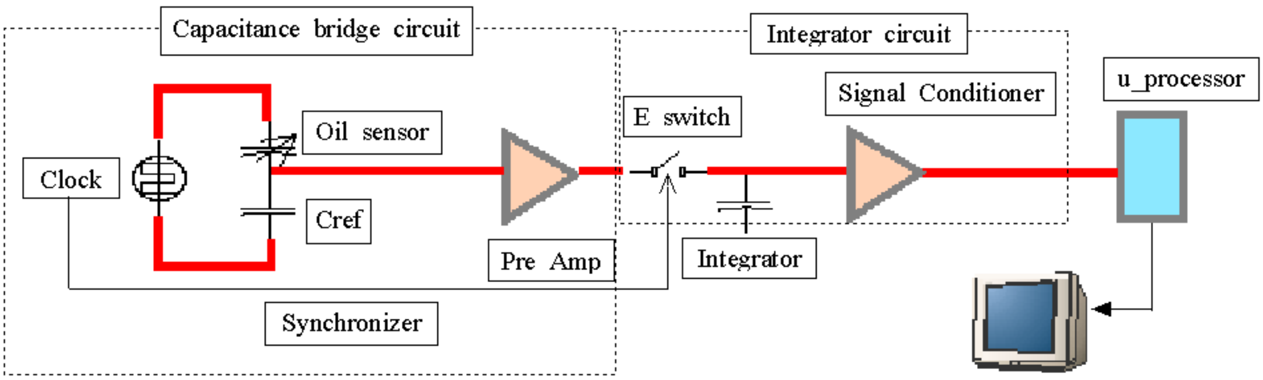



Fig. 1 Measurement principle of the deterioration of the engine oil using oil sensor for automotive

### Characteristics of engine oil

Fig. 2 shows that it is necessary to measure the temperature allowing dielectric constant measurement

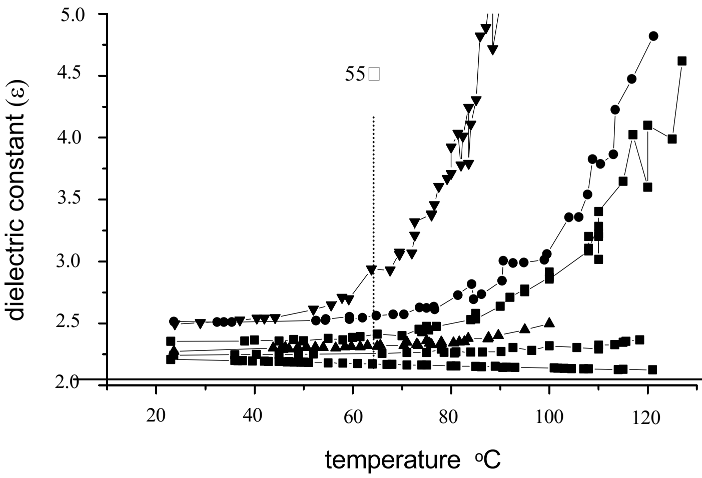



Fig. 2 Characteristics of dielectric constant vs. temperature rising of the engine oil

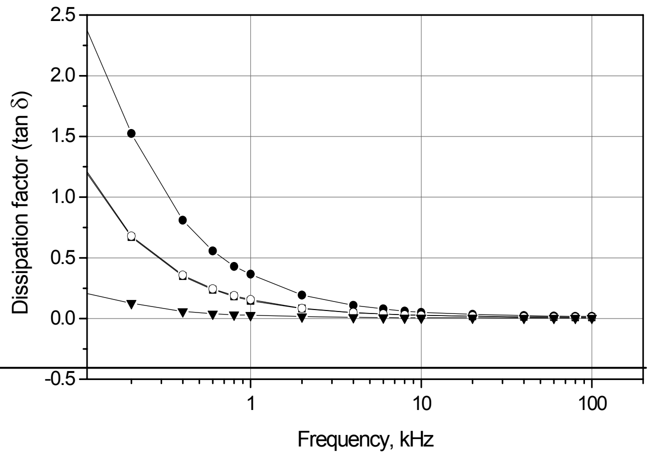



Fig. 3 Dissipation rate according to the frequency forcing to the engine oil of the automotive

within 55 ℃ when oil capacitance is measured by using the sensor developed by this study for measuring the deterioration of engine oil, since oil's dielectric constant is kept constant till 50 ℃ while oil's dielectric characteristics change at higher temperature. Engine oils used were selected randomly. Fig. 3 shows the relationship between frequency applied to engine oils and their dielectric constants. As shown in the figure, proper source frequency is 10 kHz.

## Design of Coil-typed oil sensor and Simulation

### Design of oil sensor

Based on the engine oil's characteristics of dielectric constant analyzed in the section 2, oil sensor measuring the deterioration of automobile engine oil was developed to ensure that the sensor could be installed in the drain located in the bottom of engine's oil fan. Fig. 4 shows the prototype of oil sensor. Sensing element is fixed and installed in the metal housing made for static shielding and smooth oil distribution.

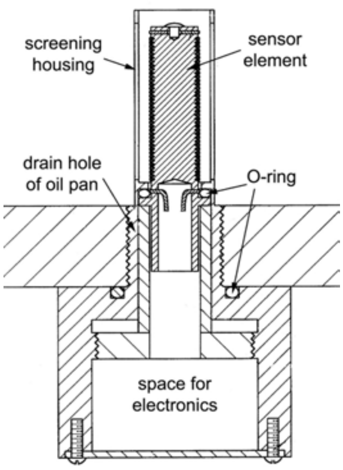
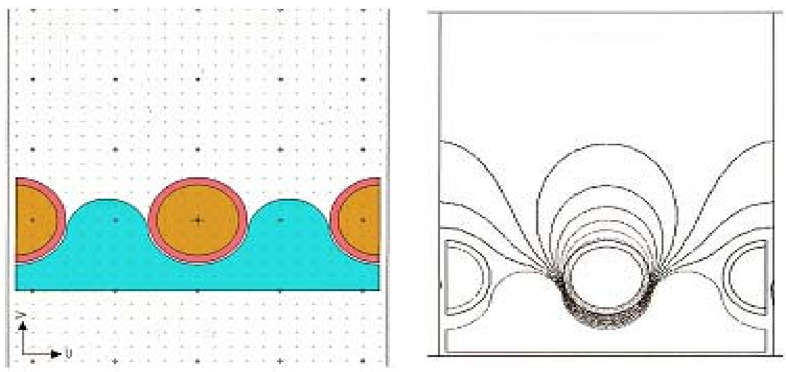



Fig. 4 Schematic Diagram of oil sensor



a) Geometry of coil threads b) Magnetic field

Fig. 5 Proto-type of the oil sensor develop

### Computer simulation

The oil sensor developed by this study is of coil type. Its capacitance is changed depending on the conditions under which coil is wound around copper former. To look for optimal conditions in winding status, this study used computer simulation in the same conditions as shown in Fig. 5 a).[6] Computer simulation of equi-potential surface with coil displacement from former was made by assuming that polyamide-applied coil winding with dielectric constant 4.2 is wound around thread type former and that the oil sensor is placed for the oils with dielectric constants 2.2 and 4.2. The simulation results are as shown Fig. 5 b), and analysis of the results is as shown in Fig. 6. Based on this, 0.1 mm coil was rolled around former with pitch spacing 0.225 mm at double thread so as to generate capacitance.

## Circuit Design for the control

### Capacitance bridge design

Capacitance bridge circuit as shown in Fig. 1 shows very large change in output voltage with changes in oil insulation resistance ($R_x$) if the resistance ($R_x$) is 300M. Therefore, the capacitance bridge circuit was redesigned so as to obtain stable output voltage, as shown below and in Fig. 7 a). Fig. 7 b) shows the result of the characteristics of oil resistance ($R_x$) when Cext is 22.0p. The characteristics shown in Fig. 7 b) mean that $R_1$ and $R_2$ have stable values at lower resistance values when $R_{ext}$ ranges between 30M and 110M.

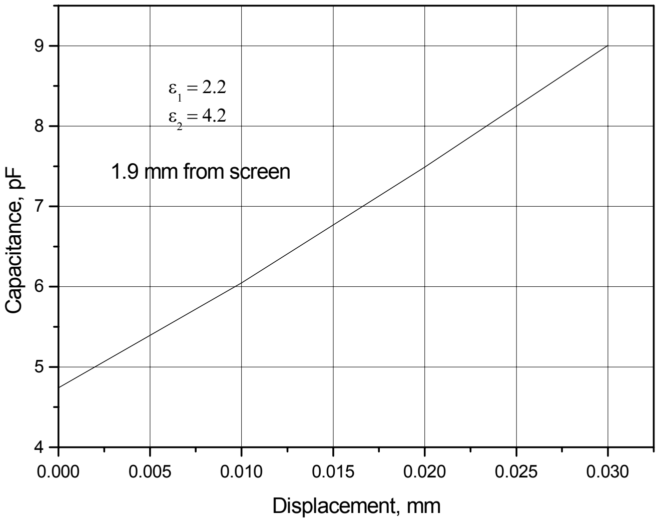
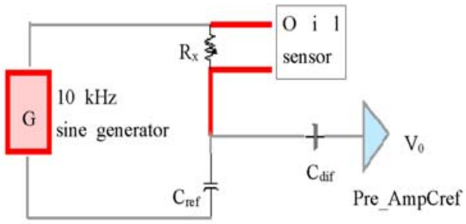
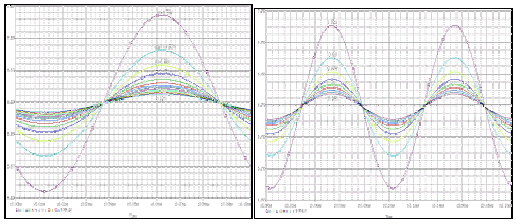



Fig. 6 Proto-type of the oil sensor develop




a) Block diagram of capacitance of bridge circuit

R1=R2=1M R1=R2=10M



b) Output of $R_x$ using the bridge

Fig. 7 Diagram and output of capacitance bridge circuit

## Integrator circuit design

In the oil sensor circuit diagram designed in Fig. 1, Integrator circuit is shown in Fig. 8. It was set to

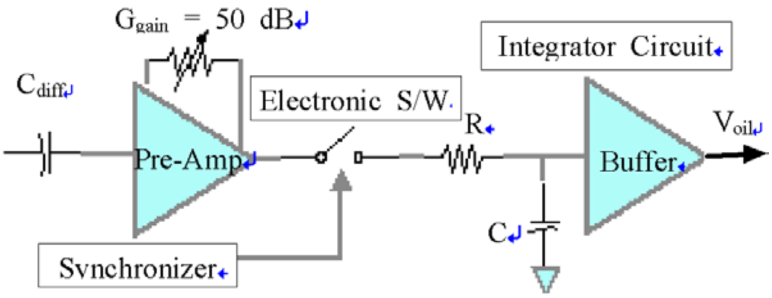



Fig. 8 Block diagram of the integrator circuit

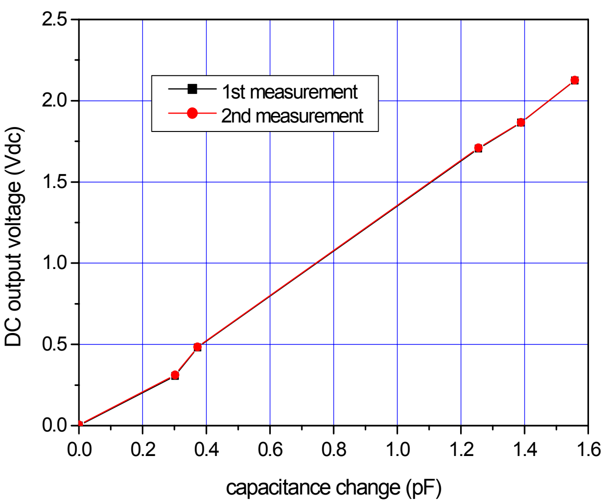



Fig. 9 DC output Voltage according to the Capacitor

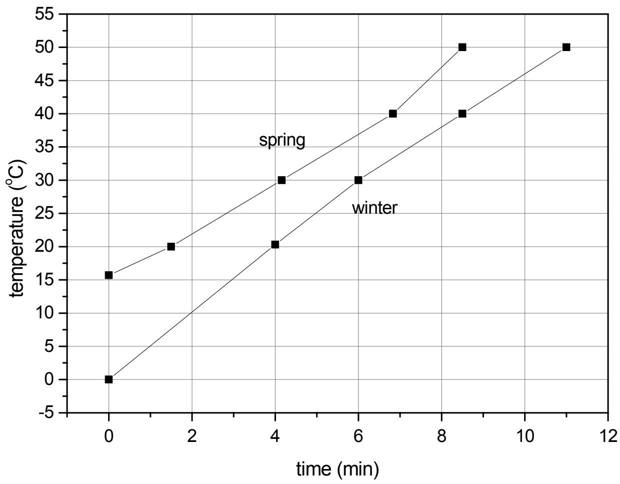
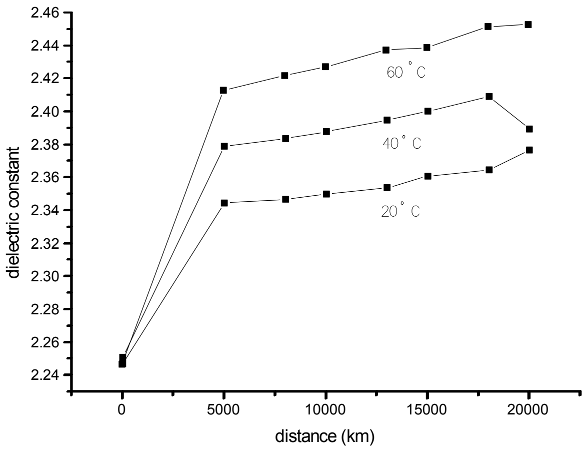



Fig. 10 Oil temperature under the driving conditions after starting the engine



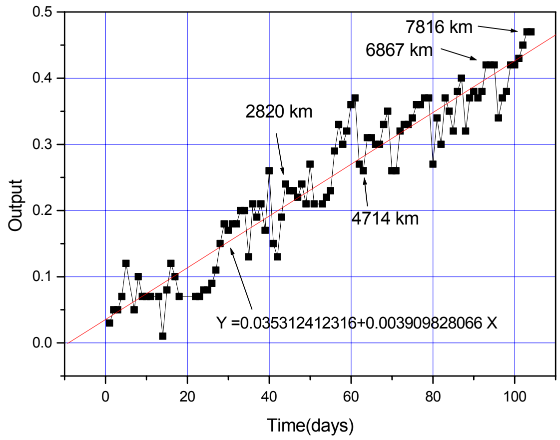




Fig. 11 Dielectric constant according to driving distance

Fig. 12 Block diagram of the integrator circuit

detect capacitance bridge circuit signal. In this case, oil value $V_{oil}$ is resulted from amplifying bridge power output ($C_{diff}$) by about 50 dB and integrating dynamic signal. As indicated in Fig. 9, output voltage (D.C.) according to the change of capacitor (pF) shows that the reappearance of the oil-sensor from the repeated experiments for different oil-type is superior.

## Conclusions and Discussions

Fig. 11 shows dielecritic constant of the engine oil according to driving distance for different oil temperature. This measurement was performed in the dynamo. As shown figure, dielectric constant of the oil is proportionally increasing with the increment of driving direction. Also, since the characteristics of oil-sensor sensitivity is directly related with temperature of the engine oil, referring to the oil viscosity, the temperature distributions of automotive engine oil in preceding the time after starting the automotive are measured from the thermostat mounted on the tip of deep gage. Fig. 10 shows the temperature rising for both spring and the winter with each different outdoor condition

Fig. 12 shows the oil deterioration degree obtained by mounting the developed oil sensor to actual cars and by converting dielectric constant to output voltage (V). Even though ages of cars, oils used, and drivers' driving habits were different, output voltage(V) of measurement device increased with driving mileage. The measurement value is resulted from the analysis of the data recorded by drivers when engine oil temperature stands between 20□ and 40□. Since mounting test was done over summer, autumn, winter and next year's spring, test was done for all conditions that the sensor installed inside cars can experience. In this case, average mileages were 8,000~9,000 km. From this, it was reconfirmed that it was possible to measure the oil deterioration by using coil type capacitance sensor.

## Results

Based on the design of coil-typed oil-sensor and circuit, it was possible to detect the dielectric constants, both of which can measure the deterioration of engine oil of cars during the driving condition of the automotive. From the experimental study, it could be concluded as followings:

(1) We developed the engine oil sensor detecting oil deterioration by using the principle that engine oil deterioration changes oil's dielectric constant, and the temperature at which dielectric constant can be measured should be within 55□.

(2) We developed the sensor's bridge circuit and integration circuit in which output voltage changes with changes in dielectric constant.

(3) Output voltage of measurement device coming from road driving test increased with mileage when engine oil temperature stood between 20□ and 40□. It is, therefore, possible to know automated oil replacement interval by setting the interval to specific output values.

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