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Promising Techniques of Automotive Engine Lubrication Oil Monitoring System – A Critical Review towards Enhancement

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Abstract

Engine lubricant plays a significant role in reducing internal friction between the piston and shear of moving mechanical parts to further improve the engine performance and efficiency. Rapid developments of engine oil monitoring systems has taken place to determine the engine lubricant degradation level in reducing unnecessary engine power loss and maintenance cost. This paper critically reviews the invention and an innovation pertaining to the subject before a smart innovation is developed in near future.

Keywords - *Automotive, engine lubricant, engine oil degradation warning system*

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I. INTRODUCTION

One of the largest areas of research, invention and innovation in the automobile industry is the engine oil monitoring. As we know, engine lubricants are complex and highly engineered fluids that are designed to allow perfect and proper engine performance over a long service time. In order to meet this goal, the lubricant is required to perform varieties of protective and functional jobs so as to provide hydrodynamic film between moving components, including heat dispensing, suspending contaminants, acid neutralization, and preventing corrosion and so on. The engine oil has a finite life as the fluid chemical and physical properties change and ultimately degrade upon usage. The typical lubricant oil can sustain between 5,000 km to 10,000 km mileage depending on the type used. The oil replacement is necessary upon reaching its useful life to maintain maximum engine protection.

In common practice, people change their engine oil at a constant time or mileage interval according to the recommendation of the lubricant oil manufacturers or vehicle original equipment manufacturers (OEMs). However, since this oil changing system is not based on the real oil condition of the specific engine, it can be replace before reaching the end of its useful life or after its useful life is exceeded. This is uneconomical as it will be a waste, and also to deteriorate the engine performance as time passes. Therefore, the lubricant oil changing alert system is introduced to provide solution on the existing problems.This system could prompt a reminder or to inform the driver for lubricant oil replacement at its final stage of useful life.

II. OIL MONITORING SYSTEM

There is a variety of oil monitoring system that have been utilized or developed. However, most of the oil monitoring systems was developed base on degradation of the engine lubricant. Several factors has been taken into consideration upon approaches towards engine lubricant monitoring research, which includes acoustic, viscosity, electrical conductivity, mathematical, temperature, multi-sensor and others. The next section will briefly review on the patents and technology which have been by previous inventor. The paper concludes with a brief discussion on future possibilities.

A. *Acoustic*

Hammond [5] presented a prototype model of an Acoustic Engine Oil Quality (AEOQ) sensor as shown in Figure 1, which utilizes changes in oil viscosity for oil quality indication. Basically , the AEOQ sensor consist of a shear mode piezoelectric sensing probe used to measure viscosity and a dedicated Voltage Control Oscillator (VCO) which allows remote excitation of piezoelectric sensing element. The AEOQ sensor is capable of discriminating between different grades of engine oils while monitoring their degradation process due to their use in automotive engine and artificial contamination by dilution with water, ethylene glycol and gasoline. The high sensitivity of AEOQ to the viscosity is because VCO simultaneously measures the merged effects of the amplitude and sensing signal phase. Apart from that, the remote access permits circuitry to be a few feet away from the harsh environment of the automotive engine. These advantages leads AEOQ to be the top setup choice over previous methods and further work will focus on the improvement of both the resolution and reliability of the sensor. However, the DC voltage signal of AEOQ varies with the surrounding temperature, therefore affecting the accuracy of the engine's oil condition final result.

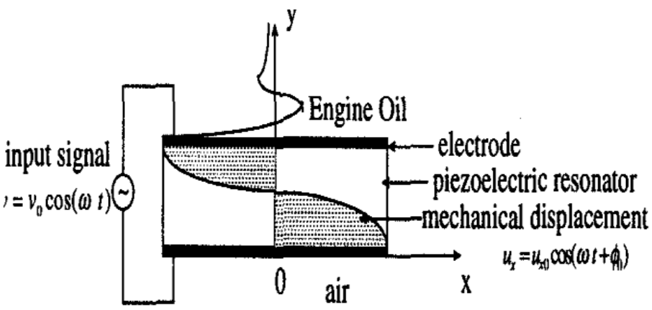

Figure 1: Cross-sectional view of the AEOQ sensing element loaded on one side by engine oil and by air on other side, [5].

Jakoby [9] conducted a research discussion focusing on the applicability of micro-acoustic viscosity sensors as shown in Figure 2 for engine oil monitoring. In the evaluation of the circumstances of automotive engine oil, one of the significant parameters is the oil's viscosity. An oil-viscosity measurement can be done via micro-acoustic viscosity sensors. As follows, the behavior of the viscosity of engine oil, its temperature dependence, and the resulting representation in terms of output signals of micro-acoustic viscosity sensors will be discussed here. Measurement results are obtained for used oil samples, which is retrieved from test cars and fresh oil samples, followed by the demonstration of the detection of the viscosity increase due to soot contamination. The application of micro-acoustic devices and their feasibility for this application are discussed here. Based on the results, Robert Bosch GmbH is currently developing a multifunctional sensor which combines a standard oil level sensor together with oil viscosity, temperature and viscosity measurement, representing a powerful new feature which is not yet discovered in current oil condition sensors.

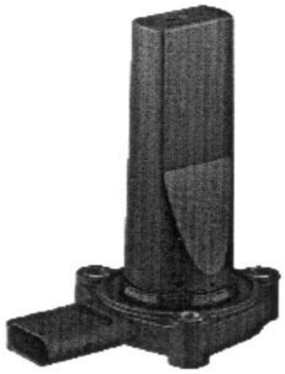

Figure 2: Housing of the oil condition sensor prototype to be inserted in opening at the bottom of the engine's oil pan, [9].

Chao [4] have investigated a micro-acoustic wave sensor based on the thickness shear mode (TSM) quartz resonator for engine oil quality monitoring through the viscosity measurement. He studied the effects of the fluid mechanical and electrical properties on the TSM resonator with both sides in contact with the fluid and compared to the 1-sided device. He developed the sensor prototypes based on both the 1- and 2- sided TSM resonators and tested in various fresh and used engine oils. Finally, he discovered that the 2-sided TSM resonator has larger viscosity sensitivity while suffers more liquid damping than the 1-sided device, not being suitable for measurement in conductive fluids. Subsequently, Chao Zhang developed the sensor prototypes for both 1- and 2-sided TSM resonators and the test results shows that they may be appropriate for providing oil quality information by monitoring the viscosity change in some applications. However, the present study also found that factors other than the oil viscosity and density may have influences on the sensor response, which indicates that the fluid knowledge is important when using such sensors for engine oil applications.

Agoston [2] has applied and interpreted the research results and discovered that there is an increasing demand for the on-line condition monitoring of lubricating oils as shown in Figure 3. Various sensors principles are taken into consideration and one of the investigated parameters are viscosity of the lubricating oil, where it can be measured via micro acoustic sensors. The research is conducted to examine the rheological domain by systematically investigating engine oils with and without additive. From the result, it is known that the viscosity of mineral base oils can be reliably measured by a micro acoustic sensor. However with the influence of polymer additives on the macroscopic viscosity, it is impossible to be detected by the sensor. Specifically, neither the thickening effect, nor the degradation of the viscosity modifier polymers is detected by micro acoustic sensor. For engine oil that contains viscosity modifier additive of higher molecular weight, the sensor output does not correlate with a conventional viscosity measurement as the sensor probes a thin oil film and thus will not detect any changes like this. It is also found that the sensor signal correlates much better with the degree of oxidation of the oil as oxidative deterioration causes an increase of the base oil's viscosity. In experiments with artificially aged oil samples it has been shown that the sensor signal correlates with the measured value of the total acid number (TAN) for artificially aged oil. The acidity of artificial aged oils is due to the oxidative degradation products of the oil itself where thermal degradation products can be detected by the micro acoustic sensor directly from the additive content of the oil. So, it can be concluded that the sensor is most likely suitable for the detection of the oxidation-induced viscosity changed changes due to thermal deterioration of the oil.

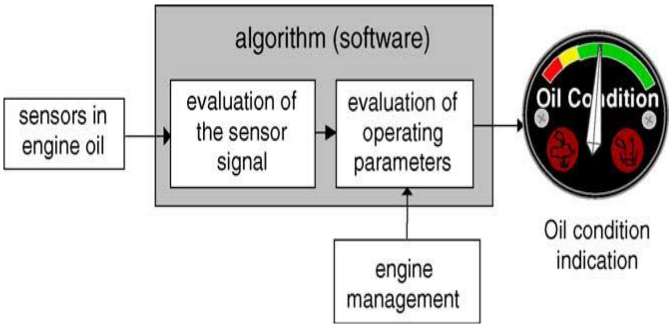

Figure 3: Structure of a sensor assisted algorithm for a lubrication-monitoring system, [2].

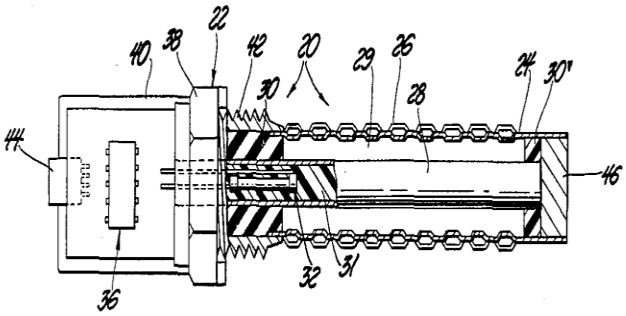

Figure 4: The oil monitor assembly constructed in accordance, [6].

B. Viscosity

Wang [17] has conducted a complementary electrochemical (EC) method to measure the Total Acid Number (TAN) of engine oil and compared it to the existing titration method in order to improve the Delphi Engine oil condition sensor which is capable of detecting three oil degradation stages: good, rapid total acid number increase, and rapid viscosity increase. Instead of titrating oil sample, the EC method applies a potential waveform to two sensing electrodes submerged in the oil sample. The TAN of the oil is then determined by the amount of current passing through the two sensing electrodes. Since a computer is used to control the entire test procedure, the TAN measured by the EC method is expected to be less operator dependent as compared to the titration method. The analysis data and the oil sensor output are then used to evaluate the TAN measured by the EC and the titration methods in order to determine the level of correlation and discussed the correlation between the TAN and the sensor output during the second oil degradation stage. Finally, the researcher has confirmed that the TAN measured by the EC method is complementary to that measured by the titration method in the end of his experiment. A good correlation was thus established between TAN and the sensor output obtained during the second oil degradation stage.

C. Electrical Conductivity

Hochstein [6] presented an engine and transmission oil degradation and temperature monitor as shown in Figure 4. The electrical circuit designed includes a degradation circuit for measuring the resistivity of the oil due to contamination and degradation while compensating for changes in resistivity of the oil due to changes in temperature. The temperature-sensitive resistor (RTS-32) is and is responsive to oil in the reservoir. The electrical circuit is responsive to the temperature-sensitive resistor (RTS-32) for providing a signal in response to a predetermined temperature sensed by the temperature-sensitive resistor (RTS-32). They claimed that contamination of the fluids in use, changes the initial resistivity at a given temperature. However, the behavior relating to decreases in resistivity with increasing temperature is still valid.

Liu [12] developed an engine lubricant warning system based on the dielectric constant. They had verified that the feasibility of the dielectric constant as the decay of lubricants evaluation index, establishes the dielectric constant three-parameter Weibull distribution model, by means of the combination of the image estimation and analysis algorithm to realize parameter prediction, determines the dielectric constant threshold based on the quality of the lubricants. During the development of the on-line warning systems for automotive lubricants, they adopt the sensor technology and integrated single-chip technology. Through the real vehicle test, this system is able to detect the lubricant decay extent reliably and real-timely, realizing "change oil by its quality" and ensuring the engine keeps in good lubrication condition all the time.

D. Mathematical

Jagannathan [8] has proposed a novel adaptive methodology where both micro-sensors and models are used in conjunction with neural network fuzzy classification algorithm to predict quality of engine oils. The condition of engine oil is defined as single variable and trended where oil condition trend was generated using a hybrid neuro fuzzy system. Advanced prognostic algorithms are applied on oil condition trends to predict remaining useful life of engine oils. They finally succeeded in proposing a hybrid approach that creates an on-board intelligent D/P system (IODPS) which can monitor engine operating conditions, measure oil parameters and correlate this information with oil condition. Further on, an advanced data analysis methods were deployed to predict remaining useful life.

Hong [7] proposed an algorithm as shown in Figure 5 to determine the suitable change time of automotive engine oil by analyzing its degradation status with mission profile data. The statistical methods used including factor analysis, discriminate and classification analysis, and regression analysis. They identify main factors of mission profile and engine oil quality with factor analysis. Subsequently, with regression analysis, they also specify relations between main factors by considering the types of mission profile of automotive: urban-mode and highway-mode. Based on them, they determine the proper change time of engine oil through discriminate and classification analysis.

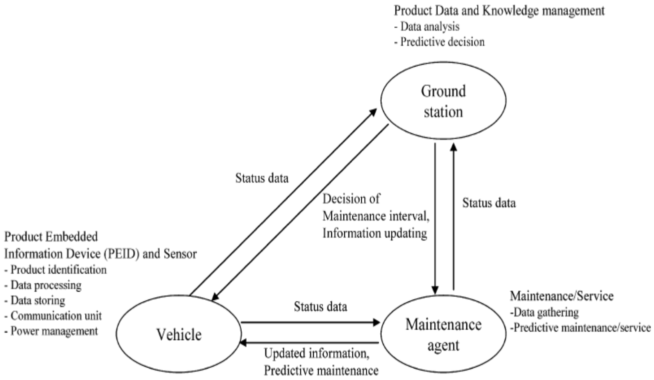

Figure 5: Predictive maintenance environment, [7].

Liu [12] have carried out a mathematical monitoring model on permittivity to evaluate lubricants quality. Furthermore, the vehicle-bone capacitive transducer and the real-time pulse width modulated (PWM) monitoring system for the quality of lubricants is designed. From the results of tested vehicles, they found and proved that the monitoring system can send out oil change alarm according to the lubricants deterioration status, thus avoid the premature replacement of good oil and the continued using of the inferior lubricants.

E. Temperature

Sawatari [15] have invented the automotive engine oil monitoring system as shown in Figure 6 to monitor and indicate the engine oil deterioration during the period of the oil's useful life in an internal combustion engine. The system and method permits a determination of the rate of deterioration of the engine oil as an oil temperature or Rpm of the engine function and provides a continuous output signal representing the remaining useful life of the oil which is provided to the driver when desired. The indication can be expressed in terms of remaining mileage, time or level of deterioration and to provide a warning to drivers before the oil reads an undesirable deterioration level. The present invention therefore, estimates the time when the oil reach an undesirable deterioration level during the course of operation of the engine rather than indicating, as many prior art systems, only when the oil reaches an undesirable level requiring an oil change.

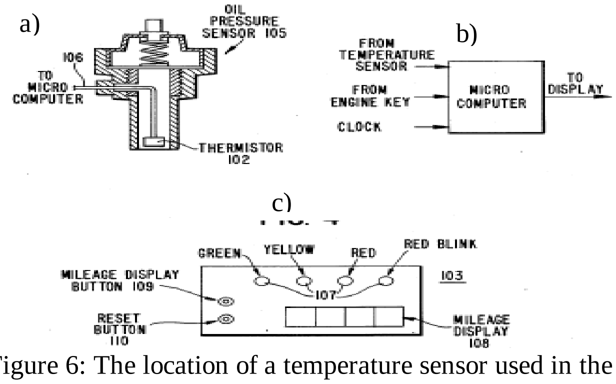

Figure 6: The location of a temperature sensor used in the subject invention (a) The inputs and outputs of a microcomputer used in the subject invention (b) The display used in the subject invention (c), [15].

Schwartz [16] have invented the Automotive Engine Oil Change Indicator as shown in Figure 7. According to the research team, the oil change can be determined by monitoring the temperature of oil, without regard to engine loading or operating conditions which are indirectly related to oil temperature variations. They claimed that excessive degradation of the engine oil occurs at its temperature extremes where at high oil temperatures, antioxidants in the oil tend to become depleted, and the oil becomes more viscous and acidic due to oxidation and nitration. In addition, insoluble particles are deposited on the engine surfaces as a varnish or sludge. At low oil temperatures, fuel, water and soot tend to accumulate in the oil, reducing its viscosity and increasing wear. In addition, acids produced by incomplete combustion reduce the ability of the oil to prevent rust and corrosion. It will be recognized, of course, that this invention may be implemented in terms of vehicle mileage as opposed to engine revolutions. In such case, the maximum oil change interval is stored in term of miles, and the effective mileage is computed according to the product of miles accumulated at a given oil temperature and the corresponding oil temperature dependent factor. While a mileage based system is briefly discussed herein, the preferred and illustrated embodiment is in the form of an engine revolutions based system.

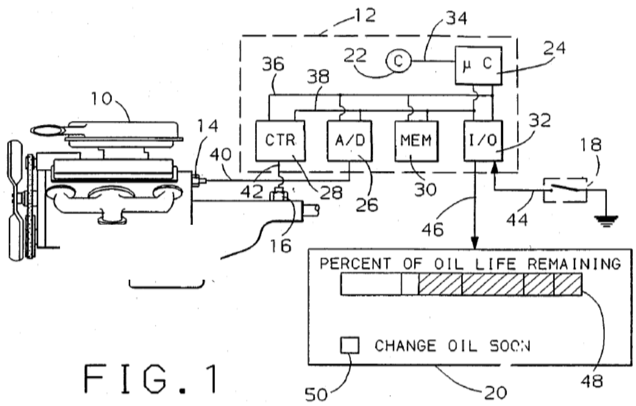

Figure 7: The schematic diagram of a computerized control unit and indicator for mechanizing the oil change indicator system of this invention, [16].

F. Multi-sensor

Kawakita [10] have developed an engine lubricant type and condition monitoring system as shown in Figure 8. This monitoring system includes a sensor which senses the grade of oil along with sensors which enable the oil change procedure per se to be detected. After each oil change the output of the oil grade sensor is read and the appropriate values which determine the limits where oil may be permitted to degraded are automatically determined. Besides that, 2 another sensors are used for sensing the level of oil in the lubricating system and sensing a parameter which varies with the rate of degradation of the oil in the lubricating system.

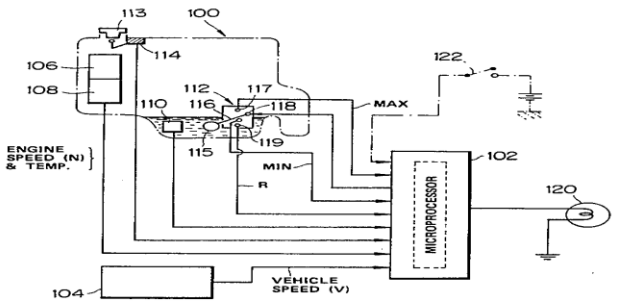

Figure 8: The schematic elevation view of an internal combustion engine equipped with a lubricant monitoring system according to the present invention, [10].

Preethichandra [14] have designed a multifunctional sensor as shown in Figure 9 to measure viscosity, cleanness, temperature and capacitance of engine oils, making a clearer decision on its condition since they discovered the uncertainties of a decision made to change the engine oil according to a maintenance schedule without analyzing the engine condition, outside temperature and usual run lengths. The designed multifunctional sensor consists of minimal and simple design for easier fabrication and lower cost but with an extensive functionality. Nonetheless, the low cost and simple data processing are the two main advantages and we can summarize that this multifunctional sensor can provide adequate information in making the best decision on the period to change the engine oil through an intelligent measuring system.

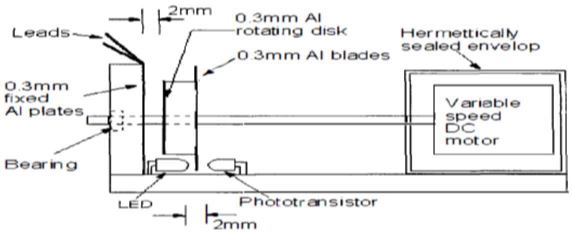

Figure 9: The designed multi-functional sensor, [14].

Agoston [1] have proposed an IR-Absorption sensor system as shown in Figure 10 for the determination of engine oil deterioration. They developed a sensor prototype setup, which determines the absorption at 5.85 µm and a reference wavelength, where the absorption is scarcely affected by oxidation. The underlying concept is suited for implementation in an online condition monitoring system. The setup involves a broadband source, a fluid cell for IR transmission through an oil sample, narrow band IR filters to select the two bands, and a broadband IR-sensor. This sensor setup potentially allows a miniaturization, which makes this concept utilizable for online monitoring of engine oil. This method can further be applied to measure further spectroscopic parameters, which can be used for engine oil monitoring, such as nitration index, soot, water and glycol content.

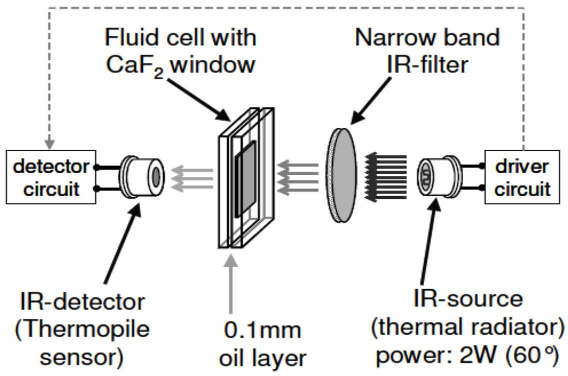

Figure 10: Working principle of the prototype sensor setup, [1].

G. Other Approaches

Aikawa [3] from Honda R&D Co.Ltd have developed a technology for estimating the base number (BN) deterioration which used as an index for judging engine oil deterioration. A detailed investigation was conducted by research team using a NO x bubbling unit and it was found that speed at which BN falls was determined mainly by heat and NO x. In addition to that, a detailed analysis was also carried and it was concluded that reduction speed can be expressed using differential rate law. Besides that, a study of the possibility of estimating reduction of the BN in an actual engine was carried out using a BN deterioration equation. The results of this study showed that it was possible to adequately estimate the BN deterioration. This indicated that it is possible to estimate the reduction of the BN on-board by the electronic control unit (ECU).

Okuyama [13] also from Honda R&D Co. Ltd have conduct another research regarding development of engine oil deterioration monitoring system using estimation method of oxidation induction time. They revealed a strong correlation between the anti-oxidation performance of engine oils and sludge production. The results of NOx bubbling tests and engine bench tests showed that the main factors in the deterioration of anti-oxidation performance are heat, air, NOx, and unburnt fuel. Detailed analysis indicated that the rate of deterioration of anti-oxidation performance could be expressed as formulas. The utilization of the deterioration rate formulas to calculate the deterioration in anti-oxidation performance in a real engine showed that the formulas could be employed in a monitoring system. They found that the use of these estimation methods of oil anti-oxidation performance by the engine control unit (ECU) would enable onboard estimation of oil deterioration.

III. CONCLUSION

Review of selected bet papers in the field of controlling engine oil quality/degradation level found that the monitoring was successfully done but not descriptive enough over the actual practical applications and unable to indicate accurate results in term of monitoring the engine lubricant as most of the systems can be influenced by surrounding conditions. On the other hand, the mathematical approach can only predict the engine oil condition base on the specific condition of the specific vehicle, while the multi-sensor system can provide a more accurate result as this kind of system determines the condition of the engine oil with few different approaches. However, there are few research gaps to be filled in for significant improvement in actual practical applications. It is intended that, a futuristic smart innovation of engine oil monitoring system to be designed where the accuracy would not directly affected by the surrounding condition such as temperature, pressure and lubricant content. Hence, the suggested approach would provide the maximum lifetime of the engine lubricant in term of total revolution experienced by the engine.

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