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Electrical Impedance Change due to Contamination at the Contact Interface of Connectors for Automobile Crank Shaft Position Sensor

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ABSTRACT

Numerous connectors are used in automobiles for transmission of electrical signals across various electro-mechanical components. The connectors must operate with high reliability in order to minimize failures due to signal degradation. In this work, the effects of contamination at the contact interface of connectors used for automobile crankshaft position sensor on the impedance change were investigated. An experimental set-up was built to simulate the electrical signal transmitted from the sensor to the engine control unit through a connector. Output from the connector was investigated using connectors contaminated with engine block residues and water droplets. It was found that slight contamination of the connectors could lead to significant signal degradation which can lead to engine failure. Also, the effect of water in the connector altered the signal severely. However, the signal gradually regained the original state as the water evaporated from the interface.

Key Words : Connector, Crankshaft position sensor, Electric contact, Impedance

1. Introduction

Electric connectors are used widely in many applications for transmission of current across two or more components. Though they may seem to be simple in construction, their importance in assuring proper operation of the system is very significant. Especially for electro-mechanical systems where small power is used in the circuit, slight alteration of the signal across the connector can be detrimental. An example of a connector where such a phenomena may occur can be found in automobile applications. This is of particular concern since automobile technology has been increasingly integrated with electronics, and therefore, the reliability of electrical components such as a connector becomes a key concern in the automobile industry. The control systems of automobile electronics operate with relatively low power and slight variation in the input/output signal can cause adverse effects on the entire system as well as pose serious concerns for the safety of the passengers.[1] In a study performed by a Korean automobile company[2] between 1998 and 2000, it was found that a major cause of automobile breakdown was due to electrical malfunction. Fig. 1(a) shows the contribution of events that led to automobile failures. It was shown that 42% of the automobile breakdown was caused by electrical malfunction. Furthermore, of the electrical malfunctions, poor contacts and shorts accounted for 90% of the failure as shown in Fig. 1(b) Thus, the performance and reliability of electrical connectors must be improved to reduce the failure rate of electrical systems.

In this work, the focus was on the connectors that are used for a crankshaft position sensor (CPS). The connectors that are used to transmit signals from the CPS to the engine control unit (ECU) typically operate at low

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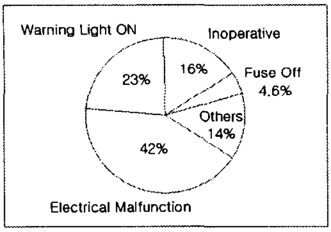
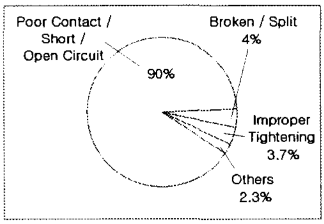


(a)



(b)

Fig. 1 (a) Contribution of various events that led to automobile breakdown and (b) major causes of electrical malfunctions in automobiles (1998-2000)

power of 0.8 mW maximum. The sensor relays information regarding the crankshaft position and engine rpm. If the signal between the two systems is degraded due to malfunctioning of the connector, engine failure can occur. CPS produces a low power alternating voltage signal which is transmitted to the ECU ranging between plus and minus 80 V depending on the engine speed. Any alteration of the electric contact interface can cause a change in the impedance or the electrical resistance of the alternating current.

Impedance of an alternating current depends not only on the resistance but also on the capacitive (X_c) and inductive (X_l) reactances of the circuit.[3] There are various studies on the effect of impedance on the contact resistance. For example, in medical equipment that deals with very small voltage signals from the human body, the change in the signal due to impedance variation must be clearly understood.[4-6] In another example, the light emitting properties of an organic-based diode depend on the impedance of the organic film between the electrodes.[7,8] The impedance at the contact region, which depends on the frequency, capacitance and inductance of the contact point, can create a relatively large noise level that can interfere with the measurement or output signal.

Connectors can lead to degradation of the electrical signal since the electrical contact interface can undergo physical and chemical changes depending on the operating condition. The electrical contact region is composed of asperity contact junctions through which current flow as illustrated in Fig. 2.[9] It should be noted that the contact interface is not smooth but consists of many asperities. Thus, there is a drop in the signal voltage across the contact interface due to the resistance associated with it.

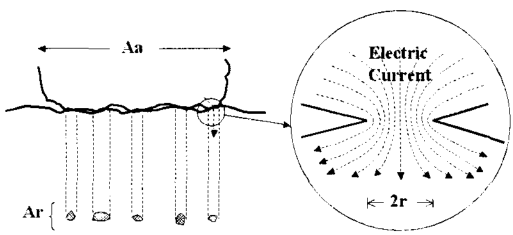


Fig. 2 Schematic of the contact region between two conducting parts with surface roughness

The electrical contact impedance can be affected by several factors such as the size and number of contact junctions, surface oxidation, and inherent resistance of the materials.[10,11] During operation, external factors such as contamination and water droplets may be introduced to the connector interface. This can cause a change in the electrical impedance of the connector. The motivation of this work is to investigate the effects of such external products entering the connector. It is suspected that a large portion of the automobile breakdown caused by electrical malfunction is due to such phenomena. Particularly in this work, contaminants in the form of engine block residues and water droplets were considered. Engine block residues can enter the connector interface during service or maintenance procedure. Also, water may enter the connector during heavy rain or car wash. Therefore, the engine block residue and water chosen for this work are things that can realistically enter the connector during operation of the automobile.

Experiments were performed to investigate the change in the impedance of a connector due to contamination and water. Contaminants and water were introduced to the connector artificially. A special electrical circuit was designed to simulate the output from a CPS of an automobile. The experimental details are described in the following sections.

2. Experimental Details

2.1 Experimental method and set-up

The connector used for this work was identical to the ones used for the CPS of an automobile. Fig. 3 shows the photographs of the male and female terminals of the connector used for the experiments.

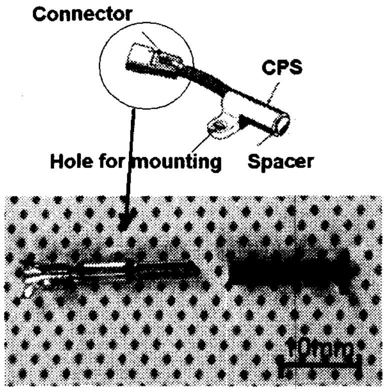


Fig. 3 Schematic and photograph of the male and female terminals of the CPS connector

The materials for the terminals were brass and copper alloy for male and female terminal, respectively. They were also coated with tin to achieve better electrical conductivity. The wires are attached to the ends of the terminals and the two are assembled by inserting the male terminal into the female one. In order to contaminate the contact region of the connector, engine block residue and water were artificially inserted into the interface of the terminals.

A special experimental set-up was designed and built to simulate the output from a CPS through the connector into the ECU. The objective was to observe whether the change in the impedance of the circuit due to the contamination of the connector will cause a failure in the operation of the ECU. Therefore, the signal from the CPS was fed into the ECU with a connector in between. Figs. 4 and 5 show the photograph and the schematic of the experimental set-up, respectively. A target wheel with 58 teeth similar to the one used in an automobile was made to rotate using a DC motor connected to it through a timing belt. The target wheel was used to generate the input signal for the CPS. The CPS was placed in proximity with the target wheel so that the signal could be picked up. The signal from the CPS was then fed to the ECU through the test connector. Also, the signal was monitored using a digital oscilloscope. The difference between the signals detected by the oscilloscope (V_c) and the signal that comes out of the connector (V_e) indicates the degree of signal degradation due to the impedance variation of the connector. The rpm indicator was used to verify the signal going into the ECU.

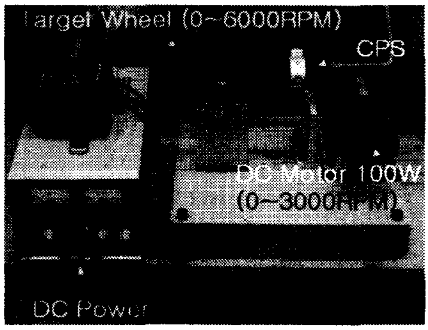


Fig. 4 Photograph of the experimental set-up

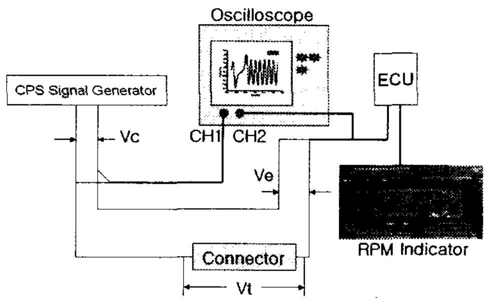


Fig. 5 Schematic of the experimental set-up

The function of the CPS in an automobile is to identify the engine speed and the position of the crankshaft so that this information can be utilized by the ECU. The ECU sends the control signals for fuel injection and spark generation based on the signal inputted from the CPS.[12] If the signal from the CPS is improper, the performance of the engine will suffer or fail completely. Fig. 6 shows a typical voltage signal (V_c) from the CPS when the target wheel is rotating at 100 rpm which was made to correspond to 1000 rpm input to the ECU. The signal is sinusoidal as expected and the magnitude of the voltage range between plus and minus 1.5 V. Thus, for a connector operating without fault, the signal V_e should be identical to V_c.

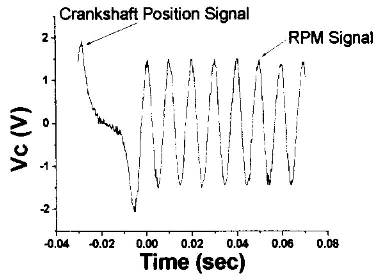


Fig. 6 Typical voltage output signal from the CPS for target wheel speed of 100 rpm (1000 rpm ECU input)

2.2 Connector contamination method

Possible sources of contamination for a CPS connector are from the residues around the engine block and water. The connectors are usually well sealed and protected from the surrounding materials. However, during service when the connector is disconnected or during heavy water splashing, contaminants may enter the interface of the connector. The probability of contamination depends on the engine operating condition and the surrounding environment. The composition of the engine block residue is usually hydrocarbon.[13] In this work, the residues found around the engine block of an automobile were sampled and used as a contaminant source for the connectors. Fig. 7 shows the chemical composition data of the engine block residue analyzed by Auger Electron Spectroscopy (AES). From the data, it can be found that the major chemical composition of the residue is carbon as expected.

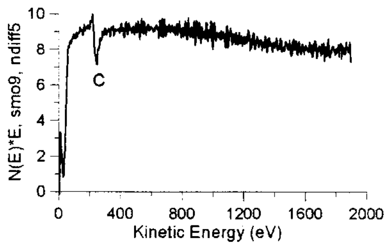


Fig. 7 Chemical composition of the engine block residue analyzed by Auger Electron Spectroscopy

Another source of contaminant used for this work was water. Water can be introduced to automobile parts under the hood due to rain or during washing. Also, during high humidity weather, water vapor can condense on the terminals of the connector. It is well known that water can cause adverse effects on the electrical signal.[14] In this work, the test connector was contaminated with water by supplying drops of water to the terminal interface which had already been contaminated with engine block residues. The impedance of the system was assessed by monitoring the output signal from the connector as a function of time as the water evaporated out of the connector interface. By doing so, the effect of residue contaminants mixed with water could be identified.

3. Experimental Results and Discussion

The connector terminals were contaminated with residues from the engine block by physically applying the residues on the terminal surfaces before being assembled. The output voltage from the CPS through the connector, V_e, was measured as shown in Fig. 8.

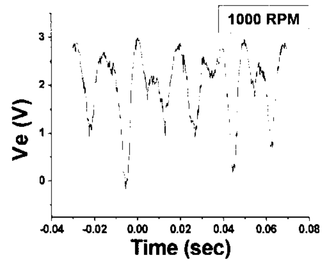


Fig. 8 Voltage signal from the connector which has been contaminated with engine block residue (1000 rpm ECU input)

As can be seen, the shape of the curve is drastically different from that shown in Fig. 6. The frequency of the signal is altered and the signal is also shifted to the positive voltage side. In this case, since the voltage output level is sufficiently high, the ECU will be able to sense the CPS signal. However, due to the change in the frequency, the ECU will assume a wrong engine speed. Though the input frequency should correspond to the speed of 1000 rpm, the ECU will assume irregular rotational speeds ranging in between tens of rpm to hundreds of rpm. The misregistration of the frequency is due to the weak variation in the voltage level over certain cycles. In order for the ECU to be able to properly count the pulse signals from the CPS, the voltage level should be lower than 0.44 V for each cycle. However, as can be seen from Fig. 8, the level of V_e signals at times 0.005 s, 0.035 s, and 0.055 s are not lower than 0.44 V. Therefore, the ECU will assume a slower rotational speed than the actual value.

The reason for such degradation in the output signal from the CPS was clearly due to the hydrocarbon contamination of the connector. The contaminants increased the impedance of the circuit and also may have influenced the circuit by the capacitance effect of the organic contaminants. In order to verify the effects of the capacitance, the capacitance at the contaminated contact region was measured together with the resistance.

In general, since electrical capacitance will be affected by the dielectric constant of a material, the intent of the experiment was to observe the change in the capacitance more clearly by changing the water content in the contaminants. After insertion of water droplets into the contact interface of the contaminated terminals, the changes in the resistance and the capacitance of the contaminated terminals were observed with respect to time as the water was being dried up.

The result plotted in Fig. 9 revealed that just after the insertion of water droplets, the resistance of the contaminated terminal decreased rapidly and the capacitance was increased suddenly. It also showed that the resistance and the capacitance had a tendency to be recovered to the values shown before the water insertion as the time for drying increased.

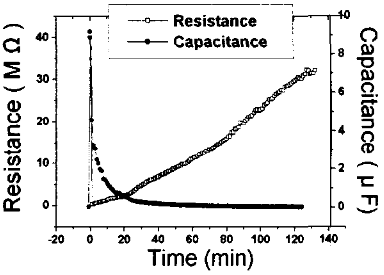


Fig. 9 Resistance and capacitance variations of the contaminated terminals wrt drying time after water insertion

The V_c and V_e signals presented in Fig. 10 are the measured signals at the time when the values of the resistance and the capacitance in Fig. 9 correspond to 3.5 MΩ and 0.4 μF, respectively. In this case, the signal waveform of V_e was quite similar to that of V_c as shown in the figure, and the impedance calculated at the frequency of 200 Hz (2000 rpm) was about 3.6 KΩ.

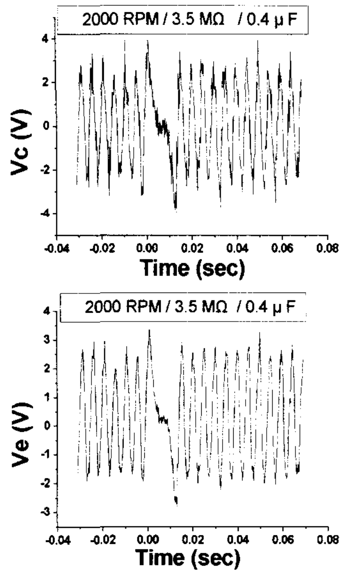


Fig. 10 Normal waveforms of V_c and V_e signals (measured at 3.5 MΩ, 0.4 μF, and 200Hz)

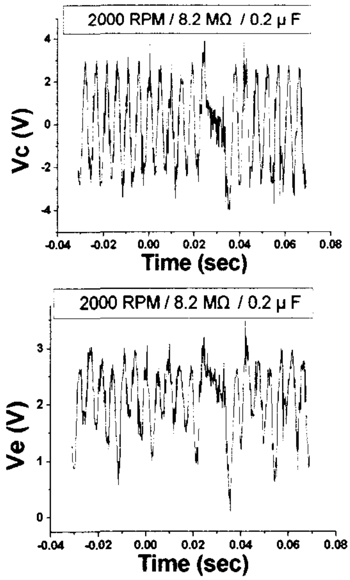


Fig. 11 Abnormal waveforms of V_c and V_e signals (measured at 8.2MΩ, 0.2μF, and 200Hz)

On the other hand, Fig. 11 shows the signals measured at the resistance and capacitance of about 8.2 MΩ and 0.2 μF, respectively. From the comparison between V_c and V_e signals, it can be presumed that ECU will indicate a wrong engine speed. The calculated impedance in this case was about 9.3 KΩ. From these observations, it can be found that the impedance at which ECU can lead to a detection error of the engine speed is quite smaller than the resistance.

The capacitance and the resistance due to the contaminants in the contact interface can be modeled as the electrical components of a capacitor and a resistor that lie in parallel in a circuit.

Fig. 12 shows the variations in the capacitive reactance, X_c, and the impedance, Z, which were calculated from the measured capacitance and resistance shown in Fig. 9. From the figure, it can be found that the variation in the capacitive reactance corresponds quite well to that of the impedance.

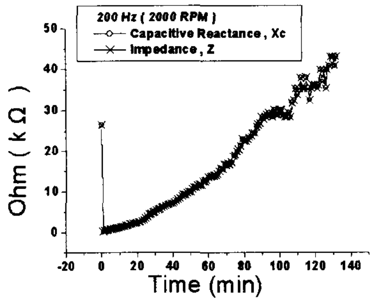


Fig. 12 Variations in the capacitive reactance and the impedance of the contaminated terminals wrt drying time

The following Eq. (1) can be used to explain the reason why the impedance is similar to the capacitive reactance.

$$Z = \frac{R \cdot X_c}{R + X_c} \approx \frac{R \cdot X_c}{R} \cong X_c \quad (R >> X_c) \quad (1)$$

Namely, it is due to the fact that the resistance is much larger than the capacitive reactance in the case of the situation mentioned here.

In conclusion, in the case of the existence of the contaminants at the contact interface that shows relatively very high resistance, the signal loss characteristics such as the distortions of waveform and frequency of the signal are mainly dependent on the capacitance rather than the resistance. To verify this conclusion more concretely, the V_c and V_e signal waveforms were investigated by the insertion of a variable resistor of 100 KΩ into the circuit, instead of the contaminated terminals. The objective was to observe only the effect of the resistance on the signal loss characteristics by removing the electrical condensing effect.

Fig. 13 is an example of the V_c and V_e signals measured at the instant when the ECU starts to indicate an error.

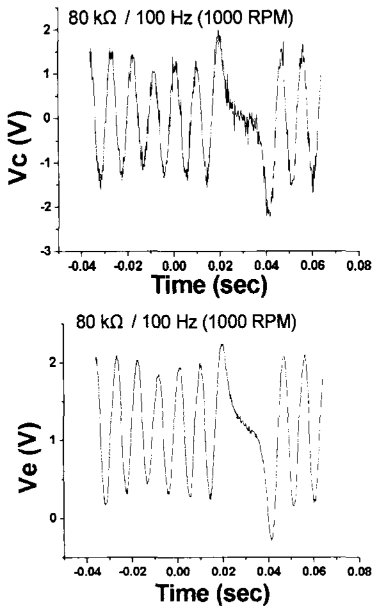


Fig. 13 Waveforms of Vc and Ve measured in the circuit using a variable resistor

From Fig. 13, it can be found that in the case that an error is only attributed to the resistance, there are only changes in the magnitude and shifting of the signal without distortion of the waveform and frequency. Also, unlike the experimental result obtained by using the contaminated terminals that shows below a few KΩ as the impedance value of an ECU error occurrence, the result obtained by using the variable resistor shows the impedance value over 80 KΩ to encounter an error in the ECU. From the results mentioned above, it can be concluded that the contaminants in the contact interface of terminals can induce an error in the detection of the engine speed by the ECU, especially even at relatively low impedance. In an electric contact situation, it is generally known that contact resistance is the only important factor for determining the signal loss characteristics. However, in the case of the contact situation with the transmission of an alternating voltage signal, care must be taken to consider the capacitance effect of the contaminants in the contact interface.

4. Conclusions

In this work, the effect of the dynamic impedance due to the surface contamination of the connector for automobile crankshaft position sensor was investigated. From the experimental results, the following conclusions may be drawn:

(1) It was found that due to the contamination of the connector terminals at the contact interface, the signal loss can occur which may lead to a system malfunction.

(2) The main cause of the signal loss such as distortions of the waveform and the frequency due to the contamination was the dynamic impedance induced by the resistance and the capacitive reactance of the contaminants. Moreover, the impedance was largely affected by the capacitance of the contaminants rather than by the relatively high resistance.

(3) The signal loss characteristics induced by electric contacts, particularly in an electrical system that transmits an alternating signal having low power, should be carefully analyzed with regard to the capacitance as well as the contact resistance of the contact interface.

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