

Effect of Gaseous Hydrocarbon-Silicon and Load Current on Contact Resistance of Electromagnetic Relays

2010-01-0204

Published
04/12/2010

Takatoshi Takikawa
AutoNetworks Technologies, Ltd.

Copyright © 2010 SAE International

ABSTRACT

Automobile engine compartments are exposed to much wider temperature and moisture-level changes than passenger compartments. Therefore, for electrical components housed in the engine compartment, protection of printed circuit boards is extremely important in order to prevent open or short circuits caused by electrochemical reactions. It is well known that silicon oxide accumulates on electromagnetic relay contacts, and may cause degraded circuits once volatile low-mass cyclic polydimethylsiloxane from a commonly used silicone gel waterproofing material reacts in a direct-current arc that occurs when the contacts open and close. Material selection for relay modules is critical in order to avoid this phenomenon. We used a gel material jointly developed with a supplier, and evaluated its reliability compared to silicone in terms of relay operation. This material is a polymer resin that consists of poly(n-butyl acrylate) as the main component, linked through silicon. According to our findings, the concentration of gaseous hydrocarbon-silicon molecules around the contacts and the load current characteristics are the key factors that interactively affect the amount of silicon oxide compound accumulation and the contact resistance. The newly developed material was adopted for relay module products because we found that it could effectively control silicon oxide compound deposits that would otherwise increase when silicone is applied and loads are switched.

INTRODUCTION

A relay module, in which electromagnetic relays smaller than conventional plug-in relays are collectively mounted on printed circuit boards (PCBs), reduces electrical circuit size and simplifies wire harness assemblies. Therefore, the relay module is especially useful in automobile engine

compartments, which are gradually becoming smaller [1,2,3]. [Figure 1](#) shows an example of relay module products.

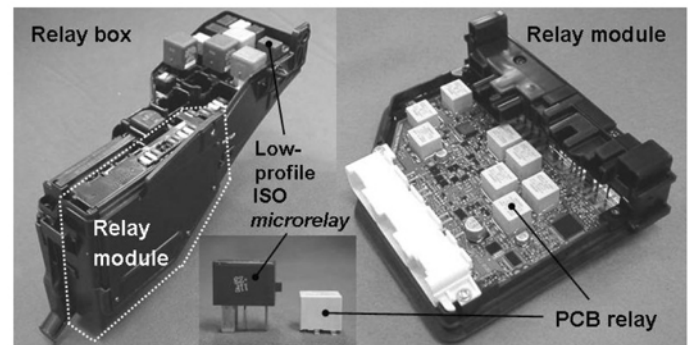


Fig. 1. Relay box and relay module

The size of the PCB-relay case is just half the size of a plug-in low-profile ISO *microrelay* [4], common in conventional relay boxes. A direct-current arc with current level and duration specific to the type of electrical load occurs when the relay contacts open and close, and erodes contact surfaces in a specific manner. This phenomenon is a factor that determines contact life. Generally, the smaller the relays are, the poorer the opening and closing ability is. Also, when relays are collectively mounted and used as a relay module that does not allow individual replacement of relays, quantitative assessment of relay failure rates is important in determining the reliability of the module [2,3]. Because the engine compartment is exposed to wider temperature and moisture-level changes than the passenger compartment, for electrical components housed in the engine compartment, PCB protection is considerable. The protection must prevent open or short circuits caused by electrochemical reactions. Mostly there are two design concepts: (1) Application of a

moisture-resistant acrylic resin film, 0.01 to 0.1 millimeter in thickness, to PCBs with mounted devices. This strategy assumes that the relay module is attached to a place that is not easily submerged; (2) Application of a waterproof gel material, in an approximately 0.1 to 1 millimeter thickness, to protect the PCBs and provide a drainage structure for the module. This strategy assumes that the inside of the relay module may become submerged. This paper discusses relay modules incorporating the second design. Silicone is a waterproof gel material commonly used in electronic components. It is well known that silicon oxide accumulates on relay contacts and may degrade the circuits once volatile low-mass cyclic polydimethylsiloxane from the silicone reacts in a direct-current arc between the contacts when they open and close [5,6,7,8]. It is critical to select a material for relay modules that avoids this phenomenon. We tested a gel material jointly developed with a supplier, and evaluated its reliability compared to silicone in terms of relay operation. After the relay operation tests, we analyzed silicon oxide deposits on the relay contacts and examined factors affecting changes in contact resistance during the tests.

EXPERIMENTAL PROCEDURES

ELECTROMAGNETIC RELAY

The PCB electromagnetic relay tested was the same relay described in previous papers [1,2,3]. It is a normally open contact type relay, with a single normally open contact pair. When the relay coil is energized, the contacts close to complete the load circuit. The contacts are mainly composed of silver, tin oxide, and indium oxide [9, 10]. The volume of the relay case (13.5 (depth) × 15 (width) × 13 (height) mm) is just half the volume of a plug-in low-profile ISO *microrelay*. Coil resistance is 220 Ω (655 mW at 12 V, 20 °C).

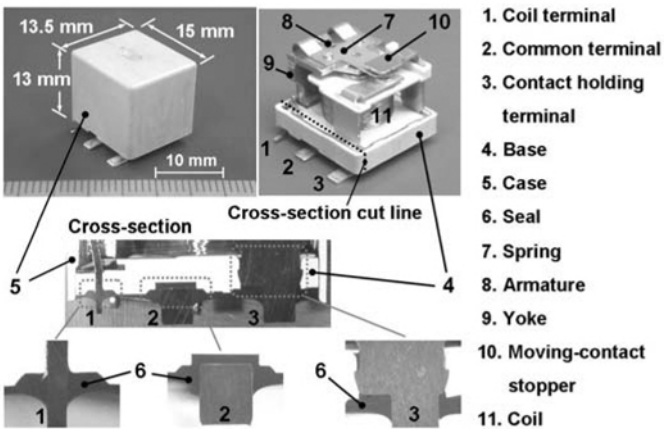


Fig. 2. Internal structure of PCB relay

Figure 2 shows the internal structure of the relay. The base and case, which are the outer components of the relay, are made of liquid crystal polymer (LCP). The base is integrated

with the coil-wire spool. The contact holding terminal, coil terminals and moving-contact stopper are inserted and fastened into holes in the base. The common terminals that are electrically connected to the moving contact are fastened to the iron yoke at the bottom of the base with caulking. The bottom of the base containing these copper-alloy terminals and the interface between the base and case are sealed with epoxy resin applied by a dispenser and then cured.

WATERPROOF GEL MATERIALS

The silicone resin and newly developed resin have molecular structures as shown in Fig. 3. They were applied to PCBs with mounted relays. The starting materials of both resins were liquid. The materials were mixed with different liquid hardeners and then applied to the PCB surfaces. They were cured into gels in an 80 °C air environment for 0.5 hour. Repetitive relay on/off operation tests were then conducted on the treated relay test samples.

Sample name	Dn-Hi, Dn-Lo	Dn-Fr
Gel material	Silicone resin	PBA-system resin
Molecular structure		
	Volatil component D_n : Cyclic structure n=3-10	D_n free

Fig. 3. Molecular structure of waterproof gel materials

The main-chain polymer structure of the silicone is polydimethylsiloxane: $[(CH_3)_2SiO]_n$. Methyl bases ($-CH_3$) from different polymers are bridged through oxidation reactions to become network structure gels. Low mass siloxane: cyclic polydimethylsiloxane (D_n : $[(CH_3)_2SiO]_n$, $3 \leq n \leq 10$) that remains after the purification process in raw material manufacturing is volatile and potentially causes electrical contact failure. In the tests, we used two types of silicone that were identified as D_{3-10} 40 ppm and 5 ppm in weight. Hereafter, the former material is abbreviated as Dn-Hi and the latter as Dn-Lo. The material jointly developed with the supplier becomes a polymer resin gel in which the ends of poly(n-butyl acrylate) (PBA), a main-chain polymer, are linked through dimethoxy-silyl bases ($=Si(OCH_3)_2$). Therefore, this PBA-system resin is free of siloxane. Hereafter, the material is abbreviated as Dn-Fr. Dn-Hi and

Dn-Lo gels are colorless and transparent. Dn-Fr gel is a light yellow and transparent. Their gel densities at 23 °C are basically the same: 0.97 g/cm³ for Dn-Hi and Dn-Lo; 1.03 g/cm³ for Dn-Fr.

TEST BOARD

Figure 4 shows the test board with mounted relays. The structure of this board is the same as boards developed for relay module products [11]. It includes the PCB and copper alloy busbars that are joined by an electrically insulating adhesive sheet. On the relay the contact holding terminal and common terminals, which act as load current paths, are soldered to the busbars and the coil terminals are soldered to the PCB. Accordingly, the load current terminals and coil terminals differ in height on the surface-mounted relay. To achieve higher heat conduction, the board is fastened to the aluminum heat sink using electrically insulating adhesive with dispersed alumina fillers.

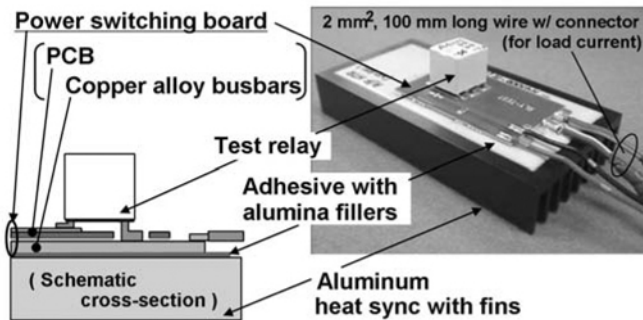


Fig. 4. Structure of relay-test board

APPLICATION OF GEL STARTING MATERIAL TO TEST BOARD

Figure 5 (a) shows the relay test sample with the waterproof gel. Before applying the gel starting material, epoxy adhesive was used to fasten the bottom case surrounding the lower part of the relay. After the gel starting material was cured, the top case was placed on the bottom case and they were sealed with polyimide tape to create the complete sample as shown in Fig. 5 (b). The material of both cases was polybutylene terephthalate (PBT) resin, which is also used for the cases of relay module products.

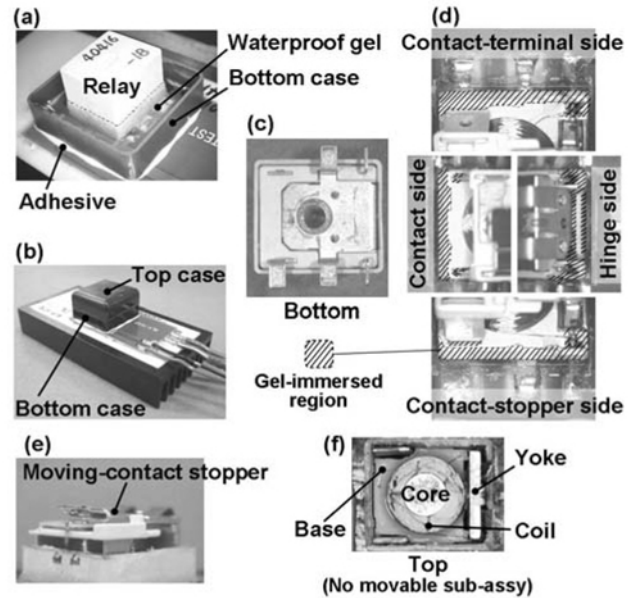
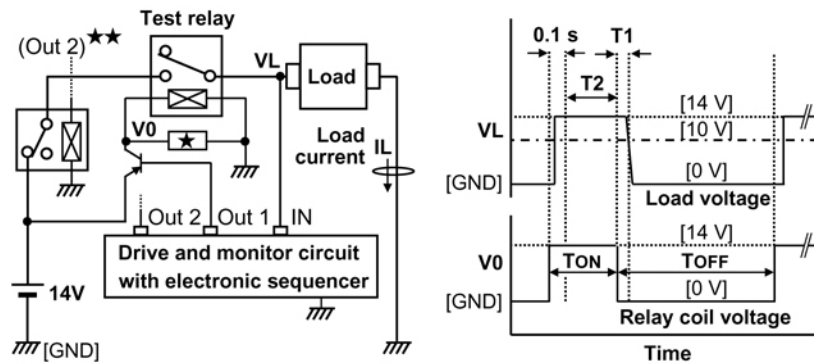


Fig. 5. Relay test sample

There are two paths through which vapor originating from the gel can enter the relay: (1) The interface between the terminal and base at the lower part of the relay that is covered with waterproof gel; the interface between the case and base; and the epoxy-resin seal of the relay (breathing); (2) The upper part of the relay case (breathing) that protrudes above the gel surface. Seal adhesion is possibly degraded by stress on the sealed interfaces due to temperature changes in the relay module manufacturing process and during actual use in engine compartments. This means that volatile molecules from the gel may directly enter the relay. Based on the above, we prepared test boards and applied the gel starting materials in two different ways: (1) Application Type A was designed by considering the maximum inflow of gel into the relay as the worst case. We used a relay in which the bottom was not sealed with epoxy, as shown in Fig. 5 (c), and applied the gel starting material. Figure 5 (d) shows how the PBA-system gel entered the relay after curing. The inflow, estimated from observation, was approximately 15 mg (1.5×10^{-2} cm³). (2) Application Type B, based on Type A, was designed to evaluate how the test results depended on the inflow of volatile molecules from the gel. We cut off the upper part of the relay case as shown in Fig. 5 (e) and poured 200 mg of gel starting material into the relay case. The gel starting material completely covered the top of the relay base as shown in Fig. 5 (f) but did not reach the moving range of the spring. We then fastened and sealed the upper part of the case to its original position with epoxy resin. Finally, we simultaneously cured the epoxy resin and the gel starting material. To avoid cross contamination of hydrocarbon-silicon between test samples, we used one curing oven for Dn-Hi and Dn-Lo, and another for Dn-Fr. Before the tests,



★ Horn load test : Diode
 Other load tests: 2.7 kΩ Resistor

★★ The relay controlled by "Out2" cuts off the current path when detecting mode, (1) or (2).

- (1) Contact interlocking detection : $VL > 10 \text{ V}$ and $T1 > 0.1 \text{ second}$
 (2) Voltage drop detection : $VL < 10 \text{ V}$ during $T2$

Fig. 6. Test circuit

we checked that the silicon contained in the test samples existed in the gel materials only.

TEST CONDITIONS

Figure 6 shows the schematic diagram of the test circuit. The signal to the relay coil (V0) was sent from a transistor switch controlled by an electronic sequencer. The operation voltage was 14 V, which corresponds to the output voltage of an alternator.

<figure 6 here>

Voltage at the load terminal (VL) was compared to the reference voltage of 10 V during operation. The sequencer stopped the relay operation (Out 1) and cut the load current path (Out 2) when the monitor circuit detected the following failures: (1) VL remained higher than the reference voltage for over 0.1 second after relay operation was shut down (welding or sticking contact failure); and (2) VL became lower than the reference voltage between 0.1 second after the relay operation was started and when it was shut down (voltage drop failure). After failure detection, the sequencer recorded the type of failure and number of cycles. If electrically insulating film on the contacts causes a degraded circuit because of volatile molecules from the gel, failure mode (2) above will be detected. To simulate engine compartment conditions, we carried out the relay operation testing in the temperature cycle environment shown in Fig. 7.

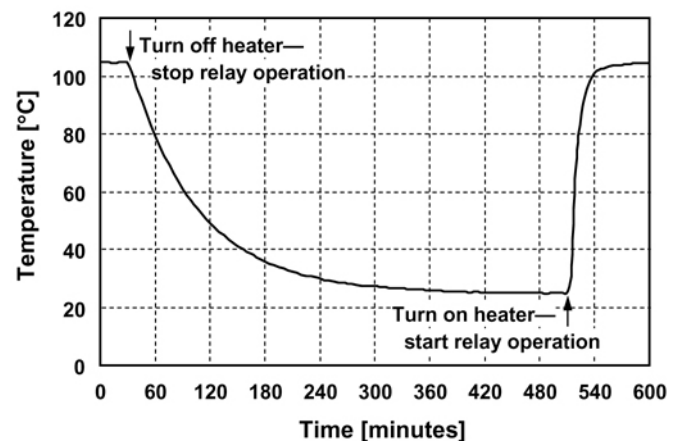


Fig. 7. Cyclic temperature change during a relay operation test

The temperature cycles in the test chamber were simply set at 25 °C for 16 hours, and 105 or 110 °C for 8 hours. We conducted the on/off operation of the relays only while the temperature was rising for approximately 0.5 hour and while the temperature was kept at 105 or 110 °C for approximately 7.5 hours. Immediately after the start of relay operation in the temperature cycle, we measured the contact voltage drop across load current terminals of the relays for the shortest interval of 24 hours and the longest interval of 72 hours.

ELECTRIC LOAD COMPONENTS

We brought four different electric load components, each having unique load current characteristics, to room temperature and used them in the tests. We used a 60 W (12 V rating) halogen bulb in the tests to verify the function reliability of the relay that repeatedly switches on and off one of two low headlight beams [12,13]. We used a high-pitched