

Factors Influencing Contact Life and Failure Mode in Compact PCB Power Relays

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ABSTRACT

Compact PCB power relays were tested in repetitious on/off operations to define their reliability through a quantitative analysis of failure cycles and an investigation of relay property changes and contact erosion forms. Operation voltage was 14 V and relay temperature was 120 °C. Ten relays were used in each of two types of load test. First failure cycles were found to be high enough for practical use, 2.2 million in the lamp load (11 A) test and 7.5 million in the test using an integrated load (10 A) comprised of engine control components. Failure mode of all relays in the lamp load test revealed contact welding, while those in the integrated load test revealed significant contact resistance due to excess erosion. Wide differences between them in contact life cycle distribution and failure mode were found to be clearly distinguishable from load current characteristics.

INTRODUCTION

Engine compartments of passenger cars, despite containing more and more components, have tended to become smaller to provide more cabin space. Because of this, the sizes of relay boxes in the compartment have had to become increasingly smaller. Accordingly, it is more effective to build a relay module into the relay box using compact electromagnetic relays mounted on a printed circuit board (PCB) in the relay module. Compactness of the relay generally decreases its electromagnetic force and as a consequence reduces its contact life in repetitious on/off operation. For this

reason, the compact relays that replace conventional plug-in types for power applications should have further advanced designs and durability testing [1] - [3]. Contact durability studies on compact PCB power relays [4], [5] with 50 percent the case volume compared to low-profile plug-in ISO microrelays [6] have been reported using automotive components representative of those in the engine compartment as the test loads. This paper describes possible factors that lead to wide differences in contact life cycles and the failure mode of relays under test conditions using two types of loads. One was a lamp load and the other one was an integrated load comprised of engine control components. Their steady currents were almost same level, around 10 A.

COMPACT PCB POWER RELAY

The compact PCB power relay tested was the same one as described in previous papers [4], [5]. It is a single normally open contact relay. When the coil of the relay is energized, the contacts mate and complete the load circuit. The contacts are mainly composed of silver, tin oxide and indium oxide [7], [8]. The case volume of the relays (13.5 x 15 x 13 mm) is 50 percent that of plug-in low-profile ISO microrelays. Coil resistance value is 220 Ω (655 mW at 12 V, 20 °C). Pull-in voltage (VP, also called minimum operating voltage) ranges from 5.0 to 6.5 V at room temperatures. Drop-out voltage (VR, also called return voltage) ranges from 1.0 to 1.5 V at room temperatures.

TEST AND EVALUATION PROCEDURES

TEST CIRCUIT

Figure 1 shows the schematic diagram of the test circuit. The signal to the relay coil was sent from a transistor switch controlled by an electronic sequencer.

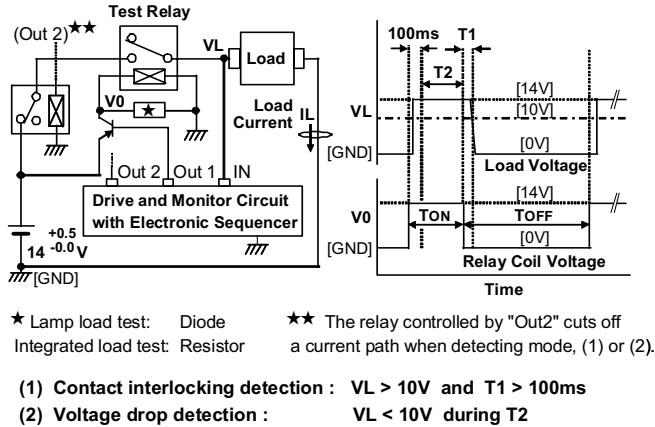


Fig. 1 Test circuit

Operation voltage ranged from 14.0 to 14.5 V, which corresponds to an alternator's output voltage. A DC power supply, capable of outputting 100 A, generated the required current for each load. Voltage at the load terminal (VL) was compared with 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 any of the following failures: (1) VL remained higher than the reference voltage for over 100 ms after the relay operation was shut down (a contact interlocking failure), and (2) VL became lower than the reference voltage between 100 ms after the relay operation was started and the moment it was shut down (a voltage drop failure). After detecting the failure, the sequencer recorded the type of failure and the number of cycles.

MOUNTING THE RELAY ON A TEST BOARD

The test relay temperature was set at 120 °C with engine compartment conditions in mind. A test relay was mounted on the power switching board that was the same as those used in the tests described in previous papers [4], [5]. This board had the same structure as the relay module product for engine compartment applications [9]. Load terminals from a surface mount device (SMD) type relay were soldered to copper busbars. Coil terminals were soldered to PCBs that were attached to the busbars with an adhesive sheet. Therefore, this SMD-type PCB relay had a step between the signal layer and the power layer. The busbars were attached to an aluminum heat spreader using an

adhesive containing alumina fillers into it to achieve high heat conduction.

ELECTRIC LOAD COMPONENTS

Two types of load components were both set at room temperature. The purpose of the lamp load durability test was to confirm the capability of the relays for switching headlight high beams in vehicles [10], [11]. This application often uses two 60 W (12 V rating) lamp bulbs. The purpose of the integrated load durability test was to confirm the capability of the main relays for switching gasoline engine control components. The load integrated three component groups that were connected in parallel. One was a set of capacitors, resistors and a Zener diode, which simulated the electronic controller unit. The second was a group of fuel injectors. The third was a set of electromagnetic actuators for engine valve control. The test relay directly supplied or cut current to all the injectors and actuators simultaneously despite the fact that in a real vehicle the ground-side transistor switch does this for each component individually.

MEASUREMENT OF RELAY CHARACTERISTICS

Relay characteristics were measured at room temperature throughout the test prior to failure occurrence of each test relay. The characteristics were VP, VR and the voltage drop across the load terminals (VD). Those in the lamp tests were measured every 100 thousand cycles and those in the integrated load tests were measured every 100 thousand cycles up to 2 million cycles, every 200 thousand cycles from 2 to 5 million cycles and every 250 thousand cycles beyond that. VR was the voltage value at which the movable contact moved away from the stationary contact when the voltage between the coil terminals was gradually reduced from 12 V. VD was the voltage value measured using the four-probe method with a voltage of 12 V and a resistive load current of 20 A. The measured VD value included the voltage drops at the power switching board busbars, the 100 mm-long 2 mm² wires soldered to the busbars, and the connector terminals.

RELAY EVALUATION AFTER FAILURE

After the case was removed from the failed relay, contact opening force (FO) and contact mating force (FM) were measured along the center axis of the contacts. Figure 2 is the diagram of those measurements. FM was measured under an applied voltage of 12 V.

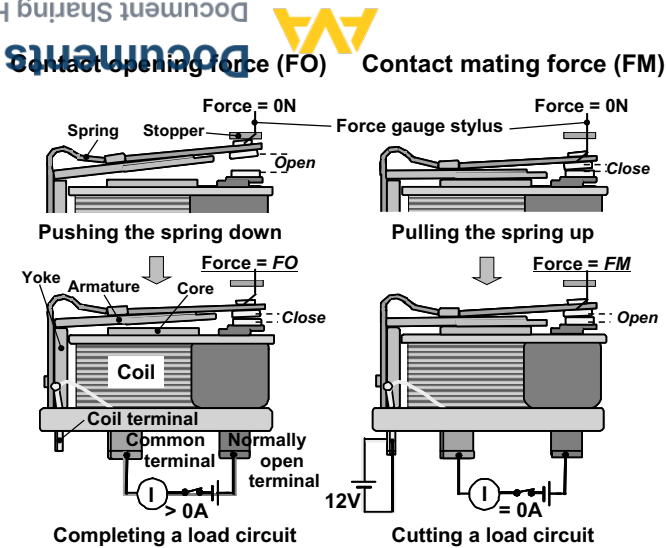


Fig. 2 Measurement of contact opening force and contact mating force of failed relay

In order to evaluate the erosion of the contacts, the contacts in the internal assembly were observed from the side using an optical microscope. After that, the terminal and the leaf spring holding the contacts were cut off from the assembly. To understand in detail the morphology of the contact erosion, the surfaces of the contacts were observed using a scanning electron microscope.

LOAD CURRENT AND VOLTAGE WAVEFORMS

Figure 3 shows the load current and voltage waveforms at the start of each test. Operation cycles were on for 0.8 seconds and off for 7.2 seconds for the lamp load, and on for 1.0 second and off for 4.0 seconds for the integrated load. Those load current paths were formed using 4 meter-long 5 mm² wires for the lamp, 5 meter-long 5 mm² wires for the integrated load. All the load components were cooled by fans throughout the tests. Each on/off cycle was determined so as to avoid a decrease of load current caused by the build-up of heat in the components. Load durability tests of relays should be conducted under constant load stress. Since the load components may degrade or become *open* in repetitive operational durability tests, the load current waveforms were displayed at all times to confirm adherence to target levels. The lamp load tests replaced bulbs every 300 thousand cycles on account of their lifespan. The integrated load tests did not need to replace the components because they could keep their initial performance up to completion of the tests. Target inrush current was kept at 70 A in the lamp load test and 30 A in the integrated load test. Their steady current was almost the same value ranging from 10 to 11 A.

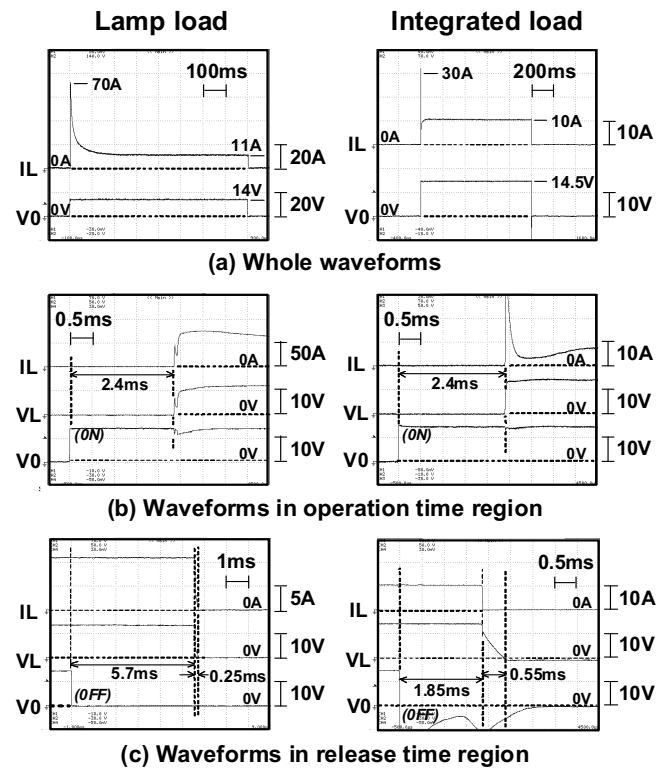


Fig. 3 Load current and voltage waveforms at test start

The relays for the lamp load test had diodes and those for the integrated load test had 2.7 k Ω resistors as surge killers during relay coil switching as shown in Fig. 1. Operation time (Fig. 3 (b)) means a period from when the relay coil is energized to the point at which the contacts mate. Both the times of the load tests were the same ranging from 2.4 to 2.6 ms because energized current through a relay coil was independent of surge killer type. Release time (Fig. 3 (c)) means a period from when the relay coil current is shut down to the point at which the contacts separate. The time in the lamp load test was around 3 times that of the integrated load test because of a flywheel-current effect by the diode connected to the coil terminals of the relays in the lamp test. Immediately after the point at which contacts separate, drop speeds of the lamp load current (IL) and VL became lower and, after that, disappeared for 0.2 to 0.3 ms. The value levels at the drop-speed change point were 2 A of IL and 3 V of VL. This indicated that the movable contact reached the stopper at that point and as a consequence the distance between contacts became constant. In contrast to these, IL for the integrated load dropped sharply after the point at which contacts started to separate. In addition, negative surges of VL induced by the solenoids [5], [12], [13] after that point did not appear. The reason why those phenomena occurred was because the Zener diode existing in the load functioned to turn the inductive current to the loop path formed with the diode and the load components. From these facts, both types of load had to give the