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Failure analysis of the electromagnetic relay contacts

Bo Wan, Guicui Fu, Yanruoyue Li *, Youhu Zhao, Meisi Jia

School of Reliability and Systems Engineering, Beihang University, Beijing, PR China

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A B S T R A C T

It is a common phenomenon that electronic components may fail after long-term storage. Users fed back that contact resistance value of several electromagnetic relays increased during the process of storage. In order to figure out the root causes of storage failure, failure analysis has been conducted in this study. Visual inspection and internal examination were carried out to observe the mechanical damage. Seal test and internal gas analysis were conducted to illustrate the situation of package and internal gas composition. The morphology and composition analysis of electromagnetic relay contacts were conducted by SEM, EDS and XPS. The results of all tests and inspections demonstrate that mechanical damage, inorganic contamination and organic contamination are the causes for the increase of contact resistance value.

1. Introduction

Electromagnetic relay is one of the most important electronic devices, which is widely used in weapon systems. For most of military electronic equipment systems, long-term storage is an essential stage during the life cycle. As a result, it is necessary to study storage reliability of electromagnetic relay, and reliability of electromagnetic relay must be paid more attention. The analysis of the storage of electromagnetic relay is helpful to improve the reliability of components which need to undergo the long-term storage.

The electrical contact failure has been one of the main aspects that affect the storage reliability of the components [1]. When users evaluate and measure the parameters of electronic components after long-term storage before on-board usage, out of tolerance always happens. In order to improve the devices' storage reliability, it is necessary to carry out failure analysis. Aimed at this situation, many scholars have conducted extensive researches on failure analysis and obtained certain achievements. According to the conclusions of literature investigation [2–4], the electromagnetic relay's common storage failure modes and mechanisms are as follows:

(i) The decline of contact reliability;
(ii) The change of appearance;
(iii) The under-proof leak rate;
(iv) Insulation property degradation;
(v) Excessive pick-up and release parameters.

The research object of this paper is a certain type of electromagnetic relay, which is used in a backup power system of small transport aircrafts. The crucial function of the device is to conserve and switch circuit while supplying power for airborne electronic equipment. As the backup power system is in a non-working condition for a long time, the electromagnetic relay experiences a long-term storage. Recently, the outputs of some circuits of the backup power have been found abnormal. This backup

* Corresponding author.

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power system has been on service for more than 6 years (55,000 h), and has not been maintained or replaced. Main missions of the aircraft are concentrated in southern China. In this region, the environment temperature can be as high as 40 °C, the surface temperature is higher than 55 °C, and the relative humidity can be greater than 80%. The air conditioning system will not be at work when there is no flight mission. Environment temperature in cabin can increase to nearly 70 °C. High temperature will accelerate fretting corrosion rate [5]. Thus the actual storage environment is a harsh condition for electromagnetic relay.

2. Experiments

A series of electromagnetic relays had experienced a long-term storage. The manufacturer is Shaanxi Qun Li Electrical Limited Liability Company. The contact material of the device is silver–nickel alloy substrate with gold coating. Electrical property tests had been carried out, and the test results showed that resistance value of several contacts exceeded the threshold. In order to distinguish the specific storage failure modes and mechanisms of the certain electromagnetic relay, the following tests have been carried out: (i) Electrical property test: In order to make sure whether the components are failure, the contact resistance value was measured and compared with the failure criteria. (ii) Visual inspection: Stereomicroscope and metallomicroscope were used to observe whether device appearance is in good condition. (iii) Seal test: This test was carried out to ensure the sealing performance. (iv) Internal gas analysis: The composition and content of internal gas were analyzed for further research. (v) Internal examination: Like visual inspection, stereomicroscope and metallomicroscope were used once again to observe internal construction and appearance. (vi) Scanning Electron Microscope (SEM) and X-ray Energy Dispersive Spectroscopy (EDS) analysis: Contact surface condition was observed under SEM and surface element was made sure through EDS analysis. (vii) X-ray Photoelectron Spectroscopy (XPS) analysis [6,7]: This test was aimed at specific elements, such as C, O, Au and Ag in this paper and it determined the chemical bond information through binding energy of each element, which can be the basis of further organic matter analysis. Contents of these tests and analysis are shown in Table 1.

3. Results and discussion

3.1. Electrical property test

The electrical property test results are represented in Table 2. The typical contact resistant value under common test condition is 5 mΩ, which is offered by the manufacturer. Actually, most of the devices' contact resistance value was greater than 35 mΩ, and 10 samples failed. According to the data obtained from the test, this type of electromagnetic relay had degraded after long-term storage.

3.2. Visual inspection

All 20 samples were examined from the aspect of appearance. Through the inspection, degradation could be obviously found.

All components' surfaces showed different degrees of oxidation. It was a common phenomenon that could cause contact failure [9]. Figs. 1 and 2 show the appearance and size of the device as well as the magnified area shown in Figs. 3 and 4. Metallic luster could not be found, as shown in Fig. 1. Desquamation and peeling are shown on the outer surface of pins of device. Typical pin degradation is shown in Fig. 3. On the other hand, as Fig. 4 shows, there is no obvious crack or big bubble in the glass insulator.

3.3. Seal test

Seal test was carried out to determine the hermeticity of sealed devices. All samples were submitted to seal test, and the results are shown in Table 3.

Table 1
The tests used in failure analysis.

Tests	Contents of tests and analysis	Failure criteria
Electrical property test	Record relevant parameters by the relay tester	50 mΩ
Visual inspection	Observe the capsulation and glass insulator	
Seal test	Fine leak test: $4.14 \times 10^5 \pm 0.14 \times 10^5$Pa 2 hour helium	$\leq 1 \times 10^{-3}$ Pa cm^3/s
	Gross leak test: $4.14 \times 10^5 \pm 0.14 \times 10^5$Pa 2 hour fluorocarbon	
Internal gas analysis	Confirm the content of nitrogen, hydrogen, oxygen, water vapor and hydrocarbon	
Internal examination	Internal pollutants; internal part deformation, damage and adhesion; internal short, open circuit and abnormal lead connection [8]	
SEM and EDS analyses	Internal pollutant composition analysis	
XPS analysis	Surface atoms and chemical bond analysis	

In total, there were 20 samples which had experienced a long-term storage. Each sample was numbered and put into the test.