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Influence of the ambient air temperature on the electrical contact reliability of electromagnetic relay

YAO Fang[†], ZHENG Jian-rong, HUANG Zhang-wu

(*People Electric Appliances Group, Yueqing 32560, China*)

[†]E-mail: yaofang72@163.com

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Abstract: The dynamic contact resistances of HH52P electromagnetic relays are measured under different ambient air temperature. Their diagnostic parameters are extracted and determined. It is found that the ambient air temperature obviously influences some parameters. In order to research its influence on the electrical contact reliability of electromagnetic relay, the statistic analysis is applied to study the static contact resistance, the max of the dynamic contact resistance and the bounce time. It is found that the ambient air temperature regularly influences the three parameters. Thoroughly, the phenomenon is studied and analyzed in the point of material science so as to probe into the essential matter of it.

Key words: Ambient air temperature, Electromagnetic relay, Electrical contact reliability, Contact resistance, Bounce time

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INTRODUCTION

Relay, one kind of low-voltage control apparatus, is widely used in many fields like automation, utility and electronics system, etc. To have a safe and reliable operation for the users, the relay must be in good performance with a long life-span (Lu and Wang, 2004). The reliability and life-span of a relay are depending on many factors, such as inherent reliability, operation condition, load category, application method, and so on. As a key factor of the operation condition, the influence of ambient air temperature on the reliability and the life-span is not negligible. At different ambient air temperature, the relays' failure mode and failure mechanism are different, which leads to the different reliabilities as well as different life-span. The relays are used all over the places in the world, so the acceptable ambient air temperature for the relays must be considered in the light of the large part of regions. Generally, it is from −25 °C to +55 °C, which is usually described in the user's menus.

For measuring the dynamic contact resistance of HH52P electromagnetic relay, a series of experiments have been carried out. Three parameters (the max of dynamic contact resistance, R_m, the static contact resistance, R_s, and the bounce time, T_b) are extracted and analyzed. The mean and standard deviations of the measured data sets of each sample are calculated. And their probability distributions at different temperature are protracted.

It is found that the statistic characteristics of these parameters are different. At different ambient air temperature, these differences are more obvious. It is to say that ambient air temperature greatly influences the static and dynamic performance of the electrical contacts. The configuration and material of electrical contacts are studied to probe the inherent reason of the ambient air temperature influencing the electrical contact reliability.

TEST, STATISTICS AND ANALYSIS

Dynamic contact resistance (Li *et al.*, 2000), R_d, is the contact resistance of a contact assembly as it opens or closes. It, of several milliohms, changes with the contact pressure between the movable contact and the immobile contact. In the closing process, the mechanical bump between the removable contact and the immobile contact results in bounce and vibrancy, so the closing is a process from dynamic bounce to static closed state. The static contact resistance, R_s, is the contact resistance of a contact assembly in the static closed state. Its value reflects the static contact performance. The lower the R_s, the better the static contact performance. R_m and T_b respectively reflect acuity and duration of bounce. They are two important parameters reflecting the dynamic electrical contact performance. The R_d-t curve includes plentiful static information and dynamic information. Three parameters, R_s, R_m and T_b, can be easily extracted from the R_d-t curve.

Tester

The dynamic contact resistance measurement system is used for monitoring, measuring, and recording R_d in the closing process from a winding being electrified to steady-going closed state on line. The measurement system takes the industrial control computer as the kernel. In addition, both modular circuits and special oscilloscope with communications I/O are outfit for measuring, memorizing and transmitting data to computer. All the actions in the process of experiment are manipulated and harmonized through the industrial control computer. The hardware frame of the device can be seen in Fig.1.

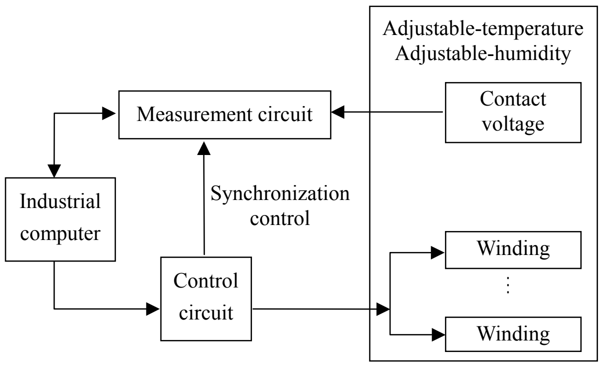

Fig.1 The hardware sketch of the dynamic contact resistance test system

Test description

The timing tailbiter experiment is taken on the HH52P electromagnetic relay (including a dozen of contact assemblies). The test conditions include 3600 cycle every hour operation frequency, rated power supply, DC24V1A resistance load. The ambient air temperatures involved are: –20 °C for Contact assembly No. 1 to Contact assembly No. 4, 20 °C for Contact assembly No. 5 to Contact assembly No. 8, and 55 °C for Contact assembly No. 9 to Contact assembly No. 12. The tailbiter cycle is 3.3 million at –20 °C, 4.92 million at –20 °C, and 1.4 million at 55 °C.

Test result

Before the tailbiter cycle, Contact assembly No. 5 is broken down at the cycle of 2.42 million because of a bad contact. So does Contact assembly No. 6 because of conglutination. The other contact assemblies run well till the expiration. Every measured R_d seems to be changing continuously and erratically with time. But all the curves show a common pattern that the value generally trails off with time from a smart bounce to a tiny fluctuation, and then approaches to a steady-going value R_s. And the duration of the process is about several milliseconds. The typical R_d-t curve can be seen from (Li *et al.*, 2000).

The test results involve 12 contact assemblies and 3350 R_d-t curves. In order to expediently study the characteristic and the trend of R_d-t curves, three parameters, R_s, R_m and T_b, are extracted from the R_d-t curves. And then the measured values series of every parameter for all contact assemblies are received. Fig.2 shows the scatter diagrams of R_s, R_m, and T_b.

Statistic character of test data

1. Mean and deviation value

The mean and the deviation are two important eigenvalues of series (Hamilton, 1995). The first one is the token of the average level while the second one is that of the discrete extent. The eigenvalue $\bar{X}$ denotes the mean of series X_i (i=1,2,…,n). The eigenvalue s denotes its deviation. The formulas for calculation are

$$\bar{X}=\frac{1}{n}\sum_{i=1}^{n}X_i, \quad (1)$$

$$s=\sqrt{\frac{1}{n-1}(X_i-\bar{X})^2}. \quad (2)$$

According to Eqs.(1) and (2), the means and the standard deviations of three parameters (R_s, R_m and T_b) are calculated and listed in Table 1.

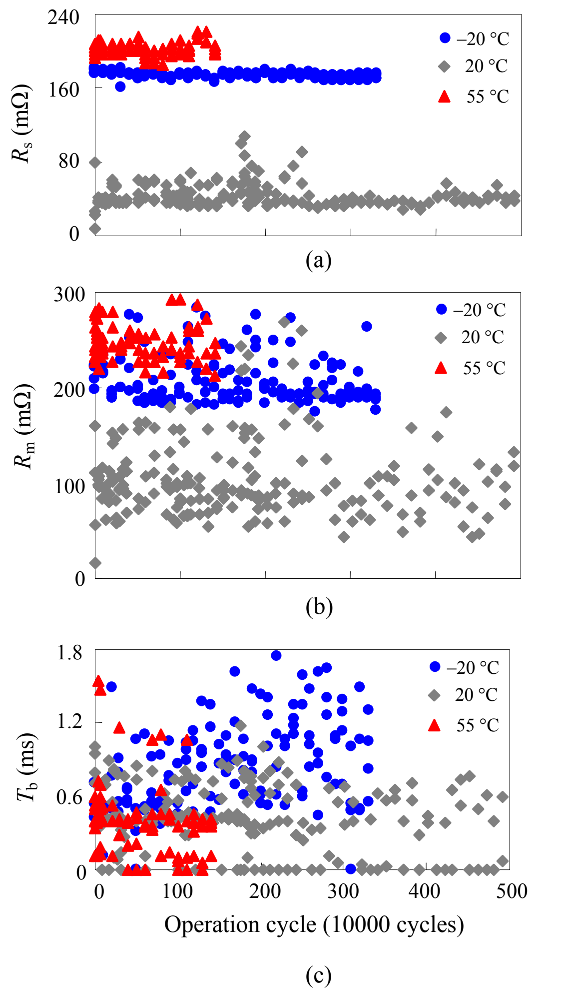

Fig.2 Scatter diagrams of (a) R_s, (b) R_m and (c) T_b at −20 °C, 20 °C, 55 °C

Table 1 Means and the standard deviations of R_s, R_m and T_b

No.	R_s (mΩ)		R_m (mΩ)		T_b (ms)	
	Mean	*s*	Mean	*s*	Mean	*s*
1	171.7	3.1	206.9	26.2	0.82	0.28
2	172.0	2.9	204.9	24.2	1.09	0.42
3	174.2	3.5	208.4	24.5	0.68	0.33
4	176.5	2.5	208.6	24.8	0.92	0.38
5	50.6	18.6	116.1	54.6	0.67	0.21
6	45.0	10.9	124.1	54.3	0.49	0.17
7	39.8	10.4	102.8	45.4	0.39	0.25
8	42.1	9.0	95.4	30.8	0.26	0.24
9	197.1	6.2	264.9	53.3	0.47	0.27
10	201.1	6.3	253.9	20.2	0.26	0.26
11	207.7	5.1	240.5	15.7	0.40	0.32
12	205.5	4.9	247.0	24.3	0.47	0.24

s is the standard deviation

Several facts can be distinctly seen from Table 1:

(1) At 20 °C, the means of R_s and R_m are the lowest, the means and the deviations of R_s and R_m of Contact assembly No. 5 and Contact assembly No. 6 are higher than that of Contact assembly No. 7 and Contact assembly No. 8. So does the mean of T_b. But the standard deviation of T_b ranges from 0.17 ms to 0.25 ms. The average of T_b in this range seems lower than that at –20 °C (0.28~0.42 ms) or 55 °C (0.24~0.32 ms).

(2) At 55 °C, the means of R_s and R_m are the highest.

(3) At –20 °C, the mean of T_b is the longest and its deviation is the biggest.

As to HH52P relay, the static and dynamic electrical contact performance at 20 °C is superior to that at –20 °C or 55 °C.

2. Probability distribution

The series X_i (i=1,2,…,n) (Hamilton, 1995) is divided into m groups according to the same distance ΔX. m_j denotes the number of data in group j. The distribution probability can be calculated by Eq.(3):

$$F_j=m_j/n, \tag{3}$$

X_{mj} is taken as the median of group j. In Eq.(3), F_j is the probability that the series data drop into the range from X_{mj}–0.5ΔX to X_{mj}+0.5ΔX. The F_j-X_{mj} curve is the probability distribution curve.

In the light of the method above, the probability distribution curves of all the data series are plotted. By contrast, the probability distribution curves of the same parameter at the same ambient air temperature seem similar to each other. To predigest the analysis, the probability distribution curves of three parameters at –20 °C, 20 °C and 55 °C are plotted in Fig.3.

The same conclusion with Table 1 can be taken from Fig.3. In addition, a newly detection is that the mean of T_b is longer and the standard deviation of it is smarter when the ambient air temperature is lower.

Configuration and material of contacts

At different ambient air temperature, the relay's static and dynamic contacts perform differently. The major reason for this is that the ambient air temperature influences the physical and electric performance of the electrical contact material.

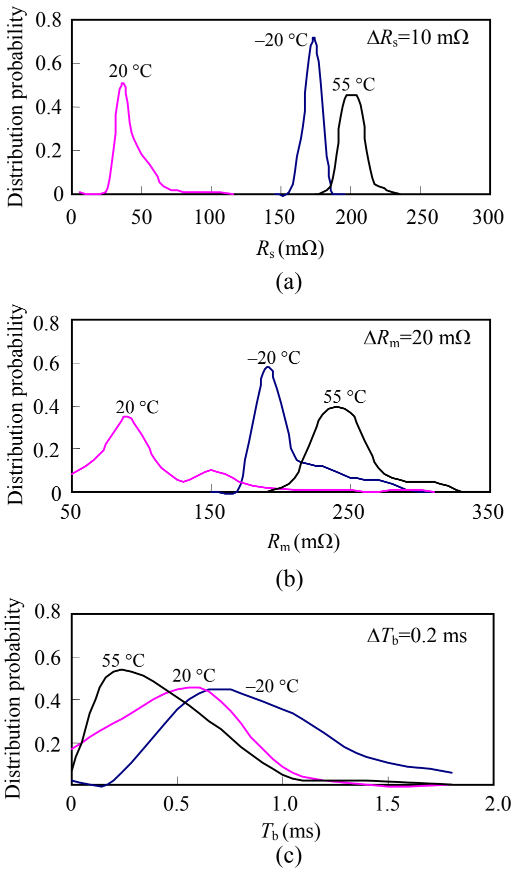

Fig.3 Probability distribution curves of (a) R_s, (b) R_m and (c) T_b at –20 °C, 20 °C, 55 °C

CONFIGURATION OF CONTACT ASSEMBLY

The HH52P relay introduces the layered composite materials, Ag-Ni10/Cu, into its electrical contact. The configuration of its electrical contact assembly is shown in Fig.4.

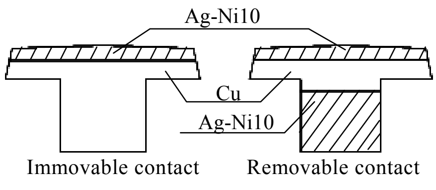

Fig.4 Configuration of contact assembly of HH52P relay

Contact material

Comparing with pure Ag, Ag-Ni alloy has higher hardness, better non-welding character, stronger abradability, longer electrical life and better plastic character (Ma, 2002), which make it be widely used as the electrical contact material for the control appliances like relay and contactors. However, due to its non-welding character, it does not meet the performance requirement of the electrical contact under high current. So it cannot be used for the contactors with high current load.

As far as Ag-Ni alloy electrical contact material concerned, the content of Ni element ranges from 5% to 60%. Ag-Ni10, Ag-Ni15, Ag-Ni20 and Ag-Ni40 are the electrical contact materials in common use. A higher Ni content in alloy results in a lower density, higher hardness and higher resistivity of the contact. Ag-Ni10 is used in the contact of HH52P electromagnetic relay in the paper. The electrical performance and physical performance of Ag-Ni10 are good enough for HH52P electromagnetic relay.

Electrical contact failure mechanism

The HH52P relay is a kind of relay with low capability. Two major problems of the electrical contact are the contact resistance and the wearing. As the removable contact bumps, its potential energy and kinetic energy are transformed into the elastic distortion energy and the plastic distortion energy. The elastic distortion leads to bounce and the plastic distortion makes the contact surface deterioration (Cheng, 1998). Accompanying it is wear and abrasion, which results in higher R_s and longer T_b (Boyer, 1994). When the wear and abrasion reach to a certain level after cycles, the electrical contact failure arises because R_s and T_b overstep their rated value.

Influence of ambient air temperature

The temperature of ambient air surrounding the electrical contact influences the contact's electric performance and physical performance. The higher the temperature is, the lower the hardness, the weaker the non-welding character, the more the abradability, and the higher the resistivity (Tamai, 1996).

On one hand, the higher R_s and R_m at –20 °C result from smaller electrical contact area caused by higher hardness. And the higher R_s and R_m, at 55 °C are caused by higher resistivity and viscidity. At 20 °C, the hardness, resistivity and viscidity of Ag-Ni10 are more acceptable so that the contact resistance is lower.

On the other hand, when the ambient air temperature increases, the elasticity of Ag-Ni10 becomes weaker and the plasticity becomes stronger. The bounce is mainly droved by the elastic distortion energy. Under very low ambient air temperature, the plastic distortion from bumping consumes rarely and the elastic distortion energy accounts for more. Accordingly, T_b under low ambient air temperature is longer.

It is to say that a proper ambient air temperature is one of the keys to insure the high reliability and long life of the electrical contact.

CONCLUSION

The main study content consists of the statistic character and the series rules of R_s, R_m and T_b under –20 °C, 20 °C and 55 °C. Some useful conclusions are drawn from analysis.

(1) When the ambient air temperature goes down, the average T_b extends longer and its dispersive degree gets worse.

(2) Comparing with three parameters under –20 °C, 20 °C and 55 °C. At 20 °C, the means of R_s and R_m are the lowest. At 55 °C, the means of R_s and R_m are the highest. At –20 °C, the mean of T_b is the longest and its deviation is the biggest.

(3) The R_s, R_m and T_b series values of broken-down contacts obviously increase with cycle. From the point of electrical contact material, the reason why the ambient air temperature influences the electrical contact performance is probed thoroughly and explained in detail.

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