Experimental Study on Discharge Characteristics of Electronic Components under Low Air Pressure in Alpine Plateau Region

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***Abstract*—Insulation characteristic is one of the key characteristics of electronic components, which directly determines the electrical safety of electronic components in use. Starting from the actual demand of poor electrical performance under low air pressure in alpine plateau regions of China, this paper chooses electromagnetic relays widely used in equipment as the research object, and carries out low temperature and low air pressure tests on them. Based on the analysis of environmental test data, the discharge mechanism of electronic components under low air pressure in alpine plateau regions is explored. The research results can be used as a reference for the rational selection of electronic components and the improvement of insulation performance in alpine plateau regions.**

Keywords-insulation; alpine plateau region; electronic components; low air pressure

I. INTRODUCTION

Electronic components refer to some parts of electrical appliances, radio, instrumentation and other industries, which are often made up of several parts and can be used in similar products. In modern society, electronic components are widely used in all kinds of mechanical and electrical products. Consequently, they are very important electrical components.

The plateau area can be regarded as an area with an elevation of more than 1000m, while the alpine area refers to the extremely cold climate area formed by the high elevation or latitude. Chinese Qinghai-Tibet Plateau is a typical alpine plateau region with very bad climatic and environment characteristics. Specific performances are as follows: low average temperature, large temperature difference between day and night; low air pressure, low oxygen content in the air; high solar radiation, high ultraviolet content[1].

Electronic components are often affected by adverse climatic factors when working in alpine plateau regions. Under the low air pressure environment in plateau, the air density is low, and electronic components are prone to air discharge, surface flashover and even insulation breakdown. Their insulation performance is greatly reduced, and the electrical safety of equipment is seriously threatened[2]. At present, many scholars all around the world have deeply studied the mechanism of gas discharge in the field of aerospace[3-6], but studies on the discharge phenomena in alpine plateau regions are few, and the research on low-pressure discharge of electronic components is more scarce.

Aiming at the influence of plateau high-cold and low-pressure environment on the insulation performance of electronic components, the low-pressure discharge characteristics of electronic components are studied in this paper, and the low-pressure discharge mechanism of electronic components in alpine plateau regions is explored, so that the selected products can meet the requirements of low-pressure environment in alpine plateau regions.

II. LOW TEMPERATURE AND LOW PRESSURE TEST

A. *Research Object and Test Equipments*

Relay is a common electronic component. All kinds of equipment working in alpine plateau region, including diverse shelters, transport vehicles, etc., of which motor, air conditioning, electric seat, electric door and window, audio, lighting and other control relays are used, so it is one of the most useful electronic components in plateau alpine equipment. Because of the unique electrical and physical characteristics of the relay in the control circuit, its high insulation resistance in the break state and low on-resistance in the state make it impossible for any other electronic components to compare with it. With the advantages of high standardization, good versatility and simplified circuits, relays are widely used in various electronic devices in aerospace, aviation, military electronic equipment, information industry and national economy.

In this paper, the electromagnetic relay widely used in equipments is selected as the research object, and the failure mechanism of high-cold and low-pressure discharge in plateau is revealed through environmental simulation test, which

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provides theoretical guidance for selecting electronic components suitable for alpine plateau regions.

The specimens and equipments used in this test are shown in Table Ⅰ. Each equipment has passed the relevant quality inspection and meets the product quality index and related technical requirements.

TABLE I. SPECIMENS AND EQUIPMENTS

Name	Model
Electromagnetic Relay	JZX-22F/2Z
Low Pressure Test Box	UD2500C-30-ESS
Insulation Withstand Voltage Tester	TH9201S

B. Test Scheme and Performance Testing

The AC voltage withstanding test of electromagnetic relay will be carried out. Because of the interaction of multiple environmental stresses in alpine plateau environment, it is not enough to study the effect of low pressure on electromagnetic relay to simulate the real climate environment. But considering the actual situation of low pressure test box, that is, low relative humidity under low pressure, it is impossible to carry out the Three-Stress comprehensive test of temperature, pressure and humidity. Apart from that, as is known to us all, the effect of low humidity on electronic components is not significant. Therefore, the temperature and air pressure test of electromagnetic relay will be studied. Specific test procedures are implemented in accordance with the relevant provisions of “Method 105 Low Pressure Test” in Standard GJB 360B-2009 “Test Method for Electronic and Electrical Components”. The experimental factors and level design are shown in Table Ⅱ. The specimens are divided into two groups. Letter a and b indicates the normally open and closed contacts and the contacts of different groups, respectively. For the two-factor test, because the number of factors is small, it is not necessary to arrange the orthogonal test, and all the tests can be carried out directly. Each factor has four levels, so the number of experiments is $4^2 = 16$. AC withstand voltage is selected as the test index. In addition, the insulation resistance of electromagnetic relay should also be measured before and after the test.

TABLE II. EXPERIMENTAL FACTORS AND LEVEL DESIGN

Factors	Level			
	1	2	3	4
A-temperature (℃)	-40	-20	0	20
B-air pressure (kPa)	25	50	75	100

The theoretical failure criterion of low pressure discharge is as follow, where U_0 denotes breakdown voltage.

$$U \geqslant U_0 \tag{1}$$

Referring to GJB 1042A-2002 “General Specification for Electromagnetic Relays”, leakage current should not exceed 100 μA for AC withstand voltage test. The specific test can be judged according to whether the leakage current displayed on the withstand voltage tester suddenly increases significantly or if the withstand voltage tester stops directly in the test work.

In order to reduce the error of test data and take into account the actual situation of the size of lead aperture in low-pressure test box, the electromagnetic relay produced in the same batch is chosen as test specimens. Three specimens are selected for each group of tests, and the data average value of three specimens is taken as the final data result under the same test conditions. Because of the need for voltage withstanding tests between normally open and normally closed contacts and between contacts of different groups, a total of 16×3×2=96 specimens are required.

III. ANALYSIS OF TEST RESULTS

The comparison of insulation resistance before and after low pressure AC withstand voltage test is shown in Figure 1 and Figure 2.

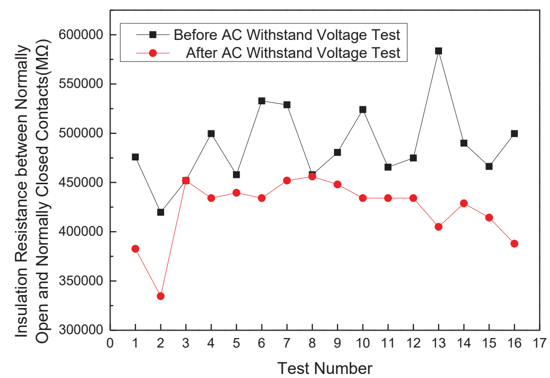

Figure 1. Variation of Insulation Resistance between Normally Open and Normally Closed Contacts before and after Test

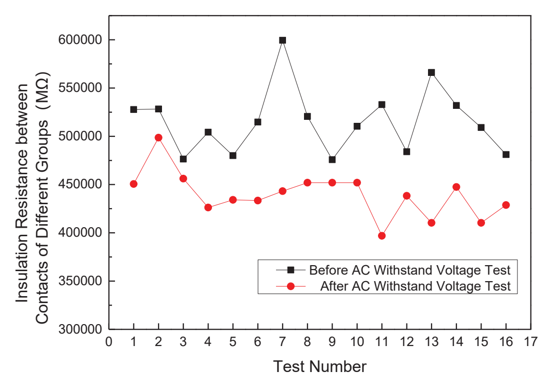

Figure 2. Variation of Insulation Resistance between Contacts of Different Groups before and after Test

It can be seen from Figure 1 and Figure 2 that although the insulation resistance of electromagnetic relay specimens decreases after AC withstand voltage test, the minimum resistance still exceeds 300 GΩ, and its order of magnitude is still hundreds of GΩ, which conforms to the rule that the theoretical resistance value should not change significantly after AC withstand voltage test. The reason is that in the process of AC withstand voltage test, when the test voltage reaches or even exceeds the breakdown voltage of insulating materials, the insulating materials suffer certain damage, while the value of insulation resistance decreases. However, because the withstand voltage tester cut off the circuit in time to avoid further high voltage damage to electromagnetic relay specimens, the range of resistance reduction is not large.

The data obtained from low pressure AC withstand voltage test of electromagnetic relay are shown in Table Ⅲ. According to the data in Table Ⅲ, the test results can be analyzed accordingly.

TABLE III. DATA OF LOW PRESSURE AC WITHSTAND VOLTAGE TEST OF ELECTROMAGNETIC RELAY

Test Number	Factors		Test Index	
No.	A（℃）	B（kPa）	U_a（V）	U_b（V）
1	20	100	1500	1500
2	20	75	1500	1500
3	20	50	1433	1500
4	20	25	1242	1467
5	0	100	1500	1500
6	0	75	1500	1500
7	0	50	1445	1500
8	0	25	1285	1418
9	-20	100	1500	1500
10	-20	75	1500	1500
11	-20	50	1401	1500
12	-20	25	1283	1350
13	-40	100	1500	1500
14	-40	75	1500	1500
15	-40	50	1438	1500
16	-40	25	1234	1242

The variation of AC withstand voltage of electromagnetic relay with air pressure at different temperatures is shown in Figure 3 and Figure 4.

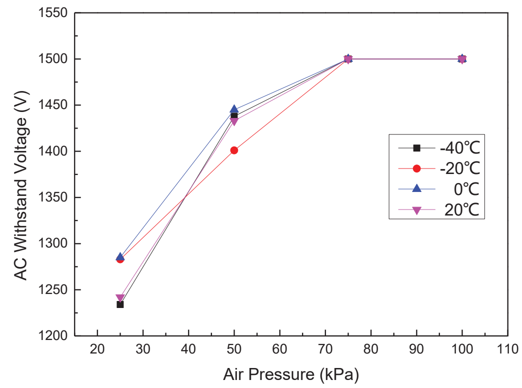

Figure 3. Variation of AC Withstand Voltage with Air Pressure between Normally Open and Normally Closed Contacts

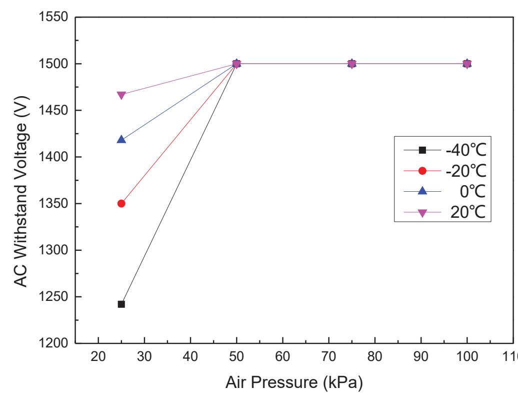

Figure 4. Variation of AC Withstand Voltage with Air Pressure between Contacts of Different Groups

It can be seen from Figure 3 and Figure 4 that the AC withstand voltage between normally open and normally closed contacts at different temperatures decreases to a certain extent when the air pressure decreases gradually from normal pressure to 50kPa. The drop rates are 4.47%, 3.67%, 6.60% and 4.13% respectively from 20 to -40℃, while the AC withstand voltage level between contacts of different groups has hardly changed, indicating that the low-pressure environment in alpine plateau regions has some influence on the AC withstand voltage of electromagnetic relays but is not obvious. When the air pressure drops to 25kPa, the AC withstand voltage level of electromagnetic relay decreases obviously at all temperatures. The decrease rates of normally open and normally closed contacts from 20 to -40℃ are 17.20%, 14.33%, 14.47% and 17.73%, respectively. The decrease rates of contacts of different groups are 2.20%, 5.47%, 10.00% and 17.20% from 20 to -40℃, respectively. Both of them decrease obviously at extremely low temperature of -40℃, which indicates that the insulation characteristics of electromagnetic relays can be adversely affected by low temperature and low pressure in high altitude environment, and it is easy to cause the discharging failure of electronic components.

The test results are analyzed by ANOVA. Specific ANOVA is shown in Table Ⅳ and Table Ⅴ, and regression models are summarized in Table Ⅵ and Table Ⅶ.

TABLE IV. ANOVA OF AC WITHSTAND VOLTAGE BETWEEN NORMALLY OPEN AND NORMALLY CLOSED CONTACTS

Source	Degree of Freedom	Adj SS	Adj MS	F Value	P Value
Temperature*	3	546	182.1	0.60	0.632
Air Pressure	3	152561	50853.7	167.00	0.000
Error	9	2741	304.5		
Total	15	155848			

TABLE V. ANOVA OF AC WITHSTAND VOLTAGE BETWEEN CONTACTS OF DIFFERENT GROUPS

Source	Degree of Freedom	Adj SS	Adj MS	F Value	P Value
Temperature*	3	7124	2375	1.00	0.436
Air Pressure	3	51287	17096	7.20	0.009
Error	9	21371	2375		
Total	15	79781			

TABLE VI. REGRESSION MODELS OF AC WITHSTAND VOLTAGE BETWEEN NORMALLY OPEN AND NORMALLY CLOSED CONTACTS

S	R-sq	R-sq（Adjust）	R-sq（Forecast）
17.4501	98.24%	97.07%	94.44%

TABLE VII. REGRESSION MODELS OF AC WITHSTAND VOLTAGE BETWEEN CONTACTS OF DIFFERENT GROUPS

S	R-sq	R-sq（Adjust）	R-sq（Forecast）
48.7295	73.21%	55.35%	15.34%

From Table Ⅳ and Table Ⅴ, it can be seen that the mean square deviation of temperature factors in both groups is less than twice the mean square deviation of error, so the influence of temperature factors on AC withstand voltage is not significant, which is treated as error. Because the P = 0.000 < 0.01 between normally open and normally closed contacts, it can be considered that the air pressure factor is highly significant; similarly, the P = 0.009 < 0.01 between contacts of different groups indicates that the influence of air pressure factor on AC withstand voltage is also highly significant. Therefore, according to ANOVA, temperature has little effect on AC withstand voltage of electromagnetic relay, which can be considered as error factor, while air pressure has significant effect on AC withstand voltage. It can also be seen from Table Ⅵ and Table Ⅶ that the goodness of fit (R-sq) between normally open and normally closed contacts is more than 98%, and the gap before and after adjustment is very small, so the regression model is better; while the R-sq between contacts of different groups is lower, the gap before and after adjustment is more than 10%, and the gap is obviously larger, so the regression model is poor.

Because the AC withstand voltage between contacts of different groups does not change obviously with air pressure, it is of little significance for further work, so the data between normally open and normally closed contacts are selected for curve fitting analysis. Using multiple linear regression model, the fitting equation is U=1226.3+0.069T+3.151p (T denotes temperature and p denotes air pressure). The fitting coefficients are analyzed and the results are shown in Table Ⅷ. It can be seen from Table 8 that, for the temperature factor, P = 0.903 > 0.05, which shows that the influence of this factor on the regression model is not significant, so the temperature factor is removed. The quadratic polynomial regression model is used to fit the AC withstand voltage and air pressure. The fitting equation is $U=1015+11.56p-0.06730p^2$. The fitting curve is shown in Figure 5, which has certain guiding significance for predicting the AC withstand voltage of electronic components under different air pressure conditions in alpine plateau regions.

TABLE VIII. ANALYSIS OF FITTING COEFFICIENT

Predictor	Coef	SE Coef	T Value	P Value
Constant	1226.3	30.7	39.89	0.000
Temperature	0.069	0.552	0.12	0.903
Air Pressure	3.151	0.442	7.13	0.000

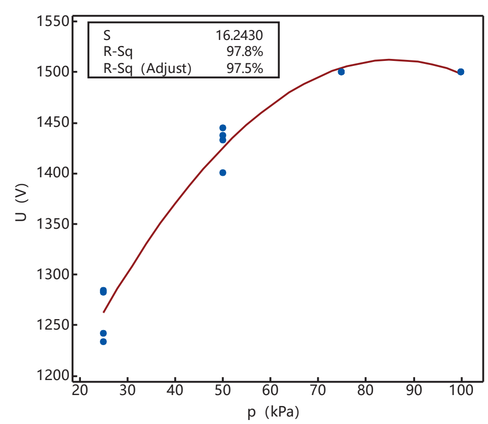

Figure 5. Fitting Curve of AC Withstand Voltage and Air Pressure

The failure mechanism of low pressure discharge will be briefly analyzed below. The significant influence of altitude on the low-pressure discharge characteristics of electronic components often occurs at high altitude or even near space[7]. Firstly, the failure mechanism of high altitude area will be analyzed. Under normal pressure, air can be used as a good insulating medium because of its high dielectric properties. However, when the altitude rises, the air density decreases so that the air pressure decreases. As a kind of dielectric, the air will gradually decrease or even lose its dielectric properties. In that way, the external insulation strength of electrical equipment with air as insulation medium, such as vacuum circuit breakers, transformers and various insulators in substations, will be significantly reduced. Relevant research shows that when the elevation does not exceed 5000m, the average air pressure decreases by 7.7-10.5 kPa and the external insulation strength of electrical equipment decreases by about 12% for each 1000m elevation rise[8]. Therefore, partial discharge and surface flashover often occur in areas with strong electric field intensity, and even insulation breakdown phenomena will also appear, which makes electrical equipment unable to work normally, and the insulation performance is seriously threatened. Secondly, the failure mechanism of near space will be analyzed. Low-pressure discharge at near space is a special form of gas discharge in low-pressure environment. According to the theory of gas pressure, when the temperature is constant, the air pressure is inversely proportional to the average free travel of electrons and the volume of gas. When the height increases and the air pressure drops, the average free travel of charged particles increases, which will accelerate the ionization of gas. Therefore, the breakdown voltage of gas decreases, resulting in a more obvious phenomenon of gas discharge.

According to the test results and failure mechanism, the insulation characteristics of electromagnetic relays are affected by low pressure environment. The higher the altitude, the easier the low pressure discharge is. However, the influence of temperature on this phenomenon is not significant. The electromagnetic relays do not have obvious AC withstand voltage reduction due to the decrease of temperature. The reason is that although many electronic components use air as insulation medium, the main effect of low temperature environment in alpine plateau regions is to compensate for the temperature rise of heat dissipation devices[9], so the effect on insulation performance is little. Therefore, with regard to the equipment working in low-pressure environment in alpine plateau regions, certain electrical corrections still need to be taken into consideration for the internal electronic components. Besides, the corresponding alpine plateau products also need to be adopted to meet the electrical working requirements of the equipment.

IV. CONCLUSIONS

Through the low temperature and low pressure test of one kind of electromagnetic relay, the regression model of AC withstand voltage and air pressure of electronic components in a certain range of air pressure is obtained. The results show that the insulation performance of electronic components of equipment working in alpine plateau area will be affected by low pressure environment. The higher the altitude, the lower the insulation performance, and the greater the risk of electrical accidents. Therefore, in the process of product design of electronic components, the regression model obtained by this paper can be referred to predict AC withstand voltage in order to improve the adaptability of alpine plateau environment. Last but not least, further research on the insulation characteristics of electronic components in alpine plateau regions can be done in mechanical stress such as vibration.

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