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Analysis of the protective effect of POLYSWITCH on resistor based on the construction of mathematical model[1]

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Abstract. The resistance value changes as the temperature increases. However, when it is beyond a certain range, the enthalpy of the resistor will continue to rise and damage may occur. In view of this, in this paper, the protective effect of POLYSWITCH on resistor was analyzed based on the mathematical model. First of all, the current status of application and research of resistor and integrated circuit in China were introduced; then, the protective effect of POLYSWITCH on resistor was analyzed based on the ANSYS mathematical model; finally, the protective effect of common thermal resistor and POLYSWITCH resistor under the ANSYS mathematical model were tested by different current values. Studies show that POLYSWITCH can make resistors more resistant to current shock and voltage resistance, thus ensuring the durability of resistors for long term use.

Key words. Construction of mathematical model, POLYSWITCH, protective function of resistor.

1. Introduction

Resistors, as a kind of important and versatile electronic components, have more than 100 years of history. The latest developments in the scale and quality of electronic resistors have reached a new level. The reliable resistors with a precision of up to 0.001 can be produced technically with a very small size, which can be adapted to the resistor network that is required for the integrated circuit. In electronic equipment, the resistance component accounts for most of the total number of electronic components [1]. Therefore, all countries attach great importance to the development of RC devices. Improving the performance is the goal of resistance devices manufacturers all over the world. They constantly study and use new materials, fundamentally improve the performance of RC components and expand their

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applications. In recent years, the components made in China are stable, and the output of the products continues to rise, moving forward at a pace of doubling in three years [2].

Metal film resistors, manufactured in 1950s, are a variety of high stability, high quality resistors. The development of integrated circuit in 1960s has made the miniaturization of electronic components in a new era. The development of large-scale and VLSI circuits in the 1980s has made profound changes in the structure of the electronics industry [3]. The advantages of integrated circuits are obvious, but the integrated circuit cannot completely replace the discrete components. There are still many components that are not integrated, and discrete components are needed to make up for them. It will take a long time for so many varieties of resistors to continue to develop, including resistor networks, potentiometers, and a variety of sensitive resistors [4].

2. State of the art

The use of POLYSWITCH thermistors for overcurrent protection is becoming increasingly widespread. In recent years, with the rapid development of science and technology and electronic communications, online distribution of the main distribution frame has reached hundreds of millions. Especially in the relatively complex environment of the rural areas, because of lightning, electromagnetic interference and power line collision, a short circuit can cause damage to the circuit board of the distribution module or switchboard, and can cause serious flame combustion [5]. All of these have caused great potential danger to communication security, so the protection of communication equipment is an important issue for the communication industry. Previously, this protection was done using a hot coil or protective circuit. Because the quality is not uniform, the protection effect is not obvious. Now using excellent UI function of POLYSWITCH components, the POLYSWITCH thermistor is designed for the over-current protection on program-controlled switches and wiring boards. The problem has been solved and the number has risen sharply [6]. At present, there are a lot of integrated circuits and modules in communication equipment. The problems, such as low working voltage, strong current and low overcurrent, exist. Relatively high lightning protection and high voltage resistance of communication lines is required [7]. The maximum rated voltage of the POLYSWITCH thermistor is between 30 V and 265 V, and the communication equipment (line) has over-current protective effect. The maximum rated voltage used by the POLYSWITCH component is between 250 V and 650 V. Therefore, the over-current protection type POLYSWITCH thermistors exhibit high temperature cycle requirements [8].

3. Methodology

3.1. ANSYS mathematical model analysis method

The most critical task of the simulation method is to construct an objective mathematical model and match the exact underlying database. Its advantage is that it provides great convenience for the future grounding resistance, structure optimization, performance simulation and so on. However, building models and basic databases takes a lot of time and cost, and the deviations between the mathematical model and the basic parameters directly affects the accuracy of the results. The ANSYS software was created and developed by Dr. John Swanson, a professor at the University of Pittsburgh in 1970. It can analyze the physical fields such as structures, heat, electromagnetic fields, fluids, acoustic fields and coupled fields. In addition, it can be used in many fields, such as mechanical, aircraft design, energy, traffic, water conservancy, architectural design, circuit simulation, medical teaching, and so on. ANSYS software provides CATIA, UG, PRO/E and other mainstream CAD software data interface. The finite element model is established to load, solve and examine the results [9].

In this study, the main steps of finite element analysis are to build finite element models, load and solve, and post process results and examine the effects. According to the analysis described in the POLYSWITCH (polymer composite thermistor), the material properties include conductivity, material density, specific heat of the material, resistivity of the material, and temperature coefficient of resistance. Applied loads include convection loads and initial temperatures [10].

The thermal field analysis of polymers is mainly determined by the physical field of polymer composites, and the thermal complex of all polymers can be analyzed by two general analytical methods: ordered polymer thermal composites and direct polymer thermal composites. The sequential polymer thermal compounding refers to that two or more physical fields are analyzed in a certain order, and then the results of the previous analysis are applied as a load to the polymer thermal fit for the next analysis. The direct polymer thermosensitive composite consists of only one analysis, and the units used contain two or more field degrees of freedom.

ANSYS software is attached with a variety of thermistor coupling units. Through the simulation experiments, it is found that solid 69 thermistor coupling unit is the most appropriate. The use of such units can be directly coupled to the current field directly on the model temperature field and operation, which greatly reduces the workload. SOLID 69 is a three-dimensional eight-node hexahedral element which consists of two degrees of freedom: voltage and temperature. It can achieve the Joule heat generated by the current, transient and steady state analyses. Common thermistors are shown in Fig. 1.

3.2. POLYSWITCH resistor protection analysis process under ANSYS mathematical model

Every ANSYS analysis must include material properties. For example, at least the relative permeability of the material is input during electromagnetic field analy-

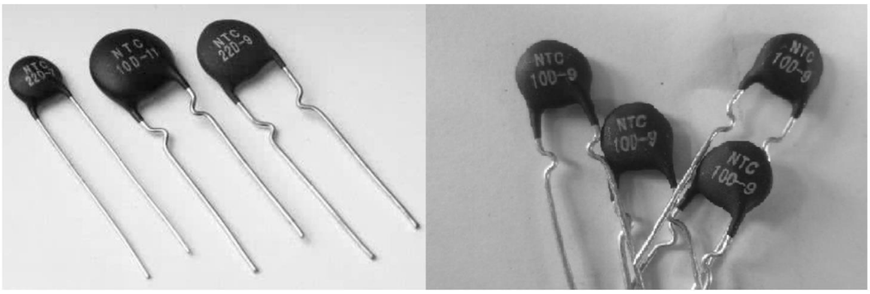

Fig. 1. Common thermistors

sis; and the modulus of the material is used as an input to structural analysis. The main components of the resistor include lead, protective layer, metal cap, melt and ceramic substrate. The main material of lead is copper, and the surface is coated with tin thin layer, the main purpose of which is to weld better. Because the tin layer is very thin, the fused wire has little influence on the fusing performance of the resistor. Therefore, the simulation results only require the material properties of copper wire, which will not affect the results of simulation.

POLYSWITCH resistance is characterized by the aspects as follows: hardness is Rockwell hardness, namely HRA80-90, which is second only after diamond and far exceeds the wear resistance of wear-resistant steel and stainless steel; abrasive resistance is excellent, the abrasive resistance of manganese steel and high chromium cast iron is very good, but the abrasive resistance of alumina ceramics is 266 times and 171.5 times than the two, and it can extend at least ten times the equipment life or more under the same operating conditions; the weight is light, and the density is half of the steel, thereby reducing the load on the equipment. The specific physical parameters of the components of the POLYSWITCH resistor are shown in Table 1.

Table 1. Specific physical parameters of the components of the POLYSWITCH resistor

Material	Density (kg/m^3)	Thermal conductivity (W/m K)	Specific heat capacity (J/kg)	Resistivity (Ωm)	Resistance temperature coefficient (TRC)
Copper	8920	400	390	1.75×10^{-8}	-
Protective layer	2650	1.3	795	-	-
Iron	7900	80	448	1.0×10^{-7}	-
Alumina ceramic	3600	25	-	-	-
Nickel chromium wire	8300	16.75	460	1.08×10^{-6}	-

Because the temperature range of the POLYSWITCH resistor melt is large, the variation of resistivity with temperature cannot be neglected. By using the following formula, the resistivity at different temperatures can be calculated.

$$\rho = \rho_0(1 + \alpha t)\,, \tag{1}$$

where ρ_0 is the resistivity of the melt at room temperature, and α is the resistance temperature coefficient.

The first is the formula method, which is used to define the relationship between parameters and temperature changes. In each step of the ANSYS iterative operation, the temperature values of each node are first read, and then the corresponding parameter values are calculated by a formula for continuous operation. If the phase transition occurs at a certain temperature, the simulation results obtained by the formula will be incorrect, because the change trend of the parameters before and after the phase transition temperature is different. Another method is the look-up table method. The physical parameter values and temperature values corresponding to the table are obtained by a test or other method in a certain temperature range, i.e., each temperature parameter corresponds to the parameter value. In calculations, the ANSYS automatically reads the temperature corresponding to the calculated parameter in the form. Melting involves phase transition. Phase change analysis must take into account the potential heat of the material, i.e., enthalpy. In ANSYS, the enthalpy of input is used as the material parameter to calculate the enthalpy of the material. Since the enthalpy is a temperature change, the enthalpy is nonlinear.

When the object is solid, the temperature is T_{S}, and the heat capacity is C_{S}. When the object is liquid, the temperature is T_τ, and the heat capacity is C_τ. The two temperatures are defined and the latent heat is obtained in the finite element analysis. The enthalpy calculation method at different temperatures is as follows:

Below the solid temperature

$$H = pC(T - T_\tau)\,. \tag{2}$$

When the object is in liquid state

$$H = H_{\mathrm{s}} + pC(T - T_\tau)\,, \tag{3}$$

The enthalpy of the body can be obtained from the above formula. The values at particular temperatures are given in Table 2.

Table 2. Values of heat enthalpy of an object at various temperatures

Temperature (K)	Enthalpy (J)
0	0
1399	5.34E9
1401	1.12E10
2000	1.42E10

In addition, meshing is a very important step in the ANSYS simulation process,

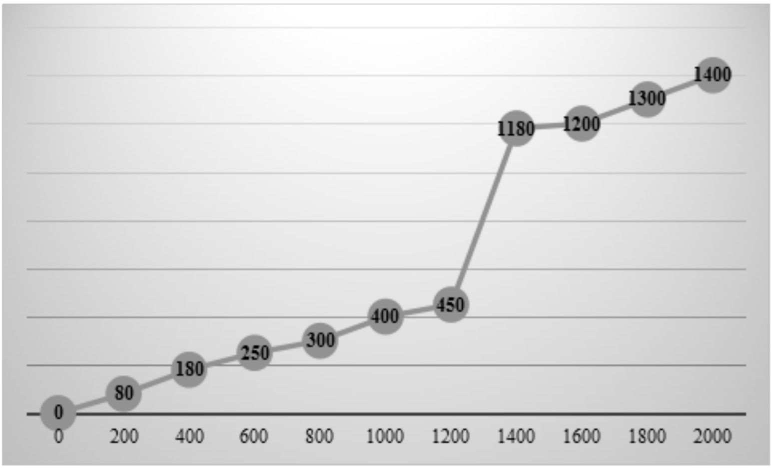

Fig. 2. Change curve of enthalpy value of resistor with temperature

because the correctness of ANSYS finite element calculation is mainly determined by the quality of the mesh. For free mesh, unit shape has no special requirement. The shape regular or irregular model can be divided into surface automatic generation triangle or quadrilateral mesh, and the body automatically generates tetrahedral mesh. The scanning mesh is mainly used in 3D model, which is to scan the whole cell from the source grid element.

For POLYSWITCH resistor, the load is first set as the initial condition. In general, the initial temperature of the model node is 20 °C. Secondly, the boundary conditions should be set up: thermal analysis conditions. Both ends of the load resistance force convection are assumed so that the temperature at both ends stays at 50 °C.

4. Result analysis and discussion

According to the project target, and combined with the current test hardware and software conditions, the project was selected through simulation test method. Through the test data, the actual heating parameters of POLYSWITCH resistance were obtained, and protection suggestions were put forward according to these parameters. According to the actual situation of the southern power grid, this study used typical structure, the hangers ZDZ66-10-10 POLYSWITCH resistors with the largest number to carry out the simulation test. The test was divided into two parts: single chip resistance heating test of common thermistor and POLYSWITCH resistance heating test.

The test was to apply frequency current on a common thermistor single resistor, so that the temperature rise of the time curve and the final heat balance temperature or blowing temperature were measured under different currents. The DZ alloy resistor which was reliably welded and secured to a special bracket was powered by a 8000 kVA test transformer and regulated with a 500 kVA regulator. The test current was monitored by the 1000/5 current transformer and the T24 ammeter. The impedance parameters of the line and equipment were obtained by several small current tests before and after the test. Then, the enthalpy and voltage of each test current were calculated. Three current values of 200 A, 300 A, and 400 A were tested each time. The results are as listed in Table 3

Table 3. Results of temperature rise test of monolithic thermistor

Current (A)	Time (s)	Hot spot temperature rise (K)	Enthalpy (J)
200 A	50	192	57
	100	307	84
	150	390	136
	200	436	172
	300	471	274
300 A	50	280	63
	100	435	89
	150	495	144
	200	530	179
	300	629	279
400 A	50	460	105
	100	660	132
	150	742	183
	200	814	229
	300	885	323

According to the results of above test several test current, it can be seen that under the action of 200 A and 300 A frequency power, the heating temperature of the hot spot is relatively mild, and the enthalpy of the two current is about 5 thresholds. The ordinary thermistor can reach the thermal equilibrium state at 373 K under 200 A power frequency. There is no abnormal heating process, and the appearance of the resistor has no obvious change after cooling. The common thermistor can achieve the thermal balance under the 300 A power frequency and the 612 K temperature. The heating time is 300 s, without abnormal heating process. After the cooling, the appearance resistance chip has slight change in color. But under the 400 A power frequency and current, the hot spot reaches 885 °C in 300 seconds, without any abnormal heating process. After cooling, the appearance color of the resistance film has changed significantly.

A frequency current was applied to the POLYSWITCH resistance to measure the temperature rise at different currents and possible thermal equilibrium temperatures. The products A, ZDZ66-10-10 type POLYSWITCH resistor was tested, which was powered by the 8000 kVA test transformer. The test voltage was adjusted by 500 kVA regulator and monitored by 1000 V current transformer and T24 ammeter. The current was tested (current was less than 100 A clamp current meter, and the test ensured measurement accuracy), and the infrared imaging equipment, automatic temperature and full video were used. Before the formal test, the impedance parameters of the line and the equipment were obtained by small current test. By calculating the test current, the voltage was applied to the required voltage. Each test was carried out in accordance with three current values of 200 A, 300 A, and 400 A. The resistor grid was only allowed to be opened in a short period of temperature measurement. The resistor gate was kept as close as possible during the rest of the time, so that the analog resistor was in the best test state. The test results are listed in Table 4.

Table 4. Test results of temperature rise of POLYSWITCH resistor

Current (A)	Time (s)	Hottest point temperature rise (K)	Enthalpy (J)	Hot spot
200 A	10	23.1	15.6	Central region
	20	48.7	25.9	Upper central region
	50	182	36.7	Upper area
	80	299	52.4	Upper area
	100	361	71.5	Uppermost central region
300 A	10	37	17.3	Central region
	20	76	29	Upper central region
	50	270	41	Upper area
	80	353	55.4	Upper area
	100	405	75.9	Uppermost central region
400 A	10	43	26.8	Central region
	20	115	43.7	Upper central region
	50	387	54	Upper area
	80	436	63.2	Upper area
	100	523	88	Uppermost central region

From the data above, it can be found that the POLYSWITCH resistor cannot achieve thermal balance in the range of 385 K under the action of 200 A frequency current. After experiencing the heating time of 95 s, the hottest point temperature rise of the resistor reaches 405 K, and the hot spot is located in the uppermost middle region. There is no abnormality during the test, and the appearance of the resistor after cooling has no obvious change. When the POLYSWITCH resistor is under the action of 250 A frequency current, the thermal balance state cannot be reached in the range of 385 K. After the heating time of 75 s, the hottest point temperature rise of the resistor reaches 405 K, and the hot spot is located in the uppermost middle region. There is no abnormality during the test, and the appearance of the resistor after cooling has no obvious change. When the POLYSWITCH resistor is under the action of 400 A frequency current, the thermal balance state cannot be reached in the range of 385 K. After the heating time of 100 s, the hottest point temperature rise of the resistor reaches 523 K, and the hot spot is located in the uppermost middle region. There is no abnormality during the test, and the appearance of the resistor after cooling has no obvious change. In summary, compared with the ordinary thermistor under the same current test condition, the POLYSWITCH resistor has lower enthalpy value, relatively stable temperature and better protective effect of the electric appliance. In addition, it has more stable physical properties and improves durability.

5. Conclusion

With the introduction of all kinds of electrical equipment, the electrical equipment commonly used in thermistors has been used for the first time to protect them. Application areas continue to expand in communications equipment. Small power input saturation and battery charger products have been applied. The fuse tube equipment can be replaced by thermistors to play over voltage protection, and over-current protection. In this paper, the protective effect of POLYSWITCH on resistor based on mathematical model was studied. Firstly, the research and application of resistors at home and abroad were introduced; then, the main steps of constructing the mathematical model were analyzed; with this model, the protection of POLYSWITCH resistor was discussed; finally, the mathematical model was used to compare the protective effects of common thermistors and POLYSWITCH resistors. Research shows that based on the role of POLYSWITCH, the associated resistors can save electricity costs and achieve a safe and efficient power plan. Therefore, the choice of POLYSWITCH resistor is the inevitable trend of the development of high-end electronic products. In addition, POLYSWITCH heating resistors need to be evenly distributed through various methods, so as to improve the reaction time and improve the working efficiency of the appliance.

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