Thermoelectrical degradation processes in NTC thermistors for in-rush current protection of electronic circuits

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Abstract

Degradation processes, caused by the extreme values of current pulses or thermal burn-in, are studied in thermistors with negative temperature coefficient of resistance. The drift of thermistor resistance at 25°C is observed. These changes depend on the value and the number of current pulses. The first 100 cycles are the basic ones for the future exploitation parameters of thermistors. Similar effect, rise of thermistor resistance, was observed after burn-in. The investigated thermistors are used for in-rush current protection of electronic circuits. © 2001 Elsevier Science Ltd. All rights reserved.

1. Introduction

Thermistors with negative temperature coefficient of resistance (NTC thermistors) are used in electronics as elements for suppression of in-rush current, relay delay, temperature control and sensing, fan control, etc. [1–3]. Low costs of manufacturing, reliability at normal conditions of exploitation (when the temperature of ceramics is lower than the critical degradation temperatures for ceramics and contact materials), simplicity are the main advantages of these devices.

At the same time the problem of minimization of thermistor dimensions (at the guaranteeing of maximum exploitation load) is actual up to now. In this connection the problems of reliability, lifetime of thermistors, determination of degradation mechanisms in ceramics, interaction of contact material and ceramic matrix, resistance to the attacks by heat, etc. are very important.

2. Experimental

The effect of cyclic switching of extreme impulse current loads (according to the method of accelerated degradation of thermistors [4]) on the power disk NTC thermistors, used for in-rush current protection of electronic circuits, is studied in this work. The changes of thermistor parameters are caused by the influence of electric fields and high temperatures, appearing due to the current heating up.

Power NTC thermistors, which are used for investigations, are manufactured from the semiconductor materials on the basis of transition metal (nickel, manganese, copper, and cobalt) oxides by the traditional ceramic technology [6–14].

Experimental samples of NTC thermistors are in the form of tablets (diameter \( D = 10 \text{ mm} \), thickness \( d = 1 \text{ mm} \)) with applied silver contact surfaces and soldered copper leads. For the protection from the influences of external factors the elements are covered by dielectric noncombustible enamel based on silicon–organic lacquer. The nominal resistance of the investigated NTC thermistors at 25°C is 16 Ω (admissible deviation within one lot is −20% to +40%).

The circuit diagram of the set, which is used for the test of NTC thermistors to the action of cyclic impulse...
current loads, is shown in Fig. 1. These investigations are realized providing the multiple charging of 270 μF capacitor by the alternating current at the input voltage $U_{\text{eff}} = 250$ V with the $f = 50$ Hz frequency through NTC thermistor and rectifying bridge. Two parallel circuits (top), commanded by rotary switch, were used to accelerate investigations of 52 thermistors, and to leave sufficient time (160 s) to cool thermistors. Multi-vibrator (bottom) produce signals for rotary switch. The maximum value of the current leaking through NTC thermistor at the moment of switching on is 22 A. This value depends strongly on the ambient temperature, because relation between thermistor resistance $R$ and temperature $T$ can be written as $R = R_N \exp(B/T - B/T_N)$, where $R_N$, $T_N$ are resistance and temperature in nominal conditions. Thermistor constant $B$ equals 3000 K. In our case the investigations are carried out at $0.5 \pm 0.5^\circ$C. Resistance was measured at $25 \pm 0.1^\circ$C. The parameters of the chosen testing conditions are considerably more rigid than the nominal working regime of these NTC thermistors (in the exploitation regime envisaged by the specifications the value of capacitance is 200 μF) [15]. The testing experiments are conducted using 26 samples of NTC thermistors chosen from one technological lot.

Moreover, thermal investigations were performed, without electrical stress. Sample of 11 thermistors was placed in thermostat. Every 24 h temperature was elevated up to $125^\circ$C during 10 h. After 2 h thermistor resistances were measured at $25 \pm 0.1^\circ$C (with HP34401A) and compared with another (“control”) sample of thermistors not submitted to this “burn-in”.

3. Results and discussion

Percent change in resistance $\Delta R/R_0$ of NTC thermistors in dependence on the number $N$ of cycles of current impulse supply (the average data for all investigated samples) is presented in Fig. 2.

Three sections for the $\Delta R/R_0(N)$ curve can be seen clearly. The first section (~0–200 cycles) is characterized by the sharp rising of $\Delta R/R_0$ value up to 3–5%. The second section (~200–700 cycles) has the relatively stable values of resistance, and the third one (more than

![Fig. 2. Percent change in resistance $(R/R_0)$ of NTC thermistors in dependence on the number $N$ of cycles of current pulse supply (average data, measured at $25^\circ$C, for investigated samples).](image-url)
700 cycles) reveals the new sharp $R$ increasing leading to the irreversible destruction of NTC thermistors.

The analogous investigations were carried out at different conditions of testing. Capacitor values were changed (240, 270, 330 $\mu$F), ambient temperature (13°C, 25°C), and voltage (250, 350 V). The character of $\Delta R/R_0(N)$ dependence did not change essentially. The difference consists only in the value of ratio of separate sections of this dependence.

So, the analysis of obtained results testifies the conclusion that the process of resistance degradation under the influence of current impulses has complex, not elementary, character and depends on the number of cycles.

Let us analyze the initial section of $\Delta R/R_0(N)$ curve ($\sim$0–200 cycles). Visual observations of outward appearance of NTC thermistors after the action of few cycles ($N = 5–20$) of electric load show the presence of bulking regions on the enamel surface of some thermistors. It can be assumed that such damages are formed owing to local electrical breakdowns of ceramic matrix. These bulking regions appear, first of all, on the edges of contact lands where the strength of electric field (mean maximal value is equal to $\sqrt{2}U_{at}/d = 354$ kV/m) may attain local maximum. At the further increasing of number of cycles (up to $\sim$100–200) the expansion of existing damaged regions and the formation of new ones is observed (Fig. 3). Microstructural investigations of ceramics (on the sections etched in 3% solution of NaCl) before and after the action of 200 cycles of electric current pulses do not show, however, the essential differences of the grain dimensions and the character of internal pores distribution.

The following section of $\Delta R/R_0(N)$ dependence (from 200 up to 700 cycles) is characterized by the relative stabilization of the observed structural transformations.

At the increasing of number of cycles up to more than 700 the appeared damages expand (their dimensions in certain cases sharply increase due to the coalescence of a few damaged regions), new defects arise along all surface of thermistor. As the consequence, the nominal resistance of these NTC thermistors leaves the limits of specified values. The occurring changes are seen especially well at the comparison of microstructure fragments for the initial and damaged NTC thermistors (Fig. 4). We can see that essential mass-transfer processes take place in the material of ceramic matrix. These processes are accompanied by the increasing of crystal-like blocks and pores dimensions, as well as the extending of intergran boundaries in the regions of surface neighboring to the regions of electrical breakdowns (black field in Fig. 4b pointed by arrows).

Fig. 3. Outward appearance of NTC thermistor after the influence of 200 cycles of current pulse loads.

Fig. 4. Microstructure of NTC thermistor samples (a) before and (b) after the influence of 1000 cycles of current pulse loads. Arrows point damage region.
Result of thermal investigations (mean relative resistance from two measurements) is presented in Fig. 5. Dependence on number of temperature cycles is clearly visible. After the first 5–8 cycles, resistance rises about 4%, similarly as after investigations with current pulses. These experiments were performed independently in different scientific centers.

Curves in Figs. 2 and 5 show very similar growth of resistance in the beginning of experiment. Current pulse causes short-time increasing of internal temperature of thermistor’s body. Thus, the rise of temperature is one of degradation factors at cyclic loads as in the case of thermal burn-in. The mechanism of this degradation can be connected with the modification of ionic distribution or the oxidation state of ceramics due to the metallization process (serigraphy) observed previously by Fritsch et al. [5] in NTC thermistors. Derivatographic investigations (DTA) are planned to find possible reasons.

Other factors of the electro-thermal degradation, as it was mentioned above, are the electrical breakdowns of ceramic matrix. This phenomenon is fully responsible for the next rise of resistance, observed after about 700 cycles of the current pulses. Material of electrodes evaporates, growth of grains and pores is observed near these places. Effective surface of cross-section leading current decreases and resistance of thermistor rises.

4. Conclusions

Process of degradation of NTC thermistors has complex character and is, in considerable degree, determined by the total number of applied current impulses or thermal cycles. Initial rise of resistance is caused probably by oxidation process or modification of ionic distribution. It must be verified by additional investigations. Thermistor destruction is connected with electrical breakdown of ceramic matrix on the edges of contact land and has the main role for the further changes of thermistor’s electrical parameters. At the sharp increasing of number of impulses (more than 700) the irreversible mass-transfer processes in ceramics are essential. It leads to the considerable increasing of NTC thermistor resistance.

References

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