*Journal of Engineering Physics and Thermophysics, Vol. 75, No. 5, 2002*

# ELECTROPHYSICAL CHARACTERISTICS OF A POSISTOR BLOCK

**S. R. Syrtsov, V. N. Shut,**
**D. A. Il'yushchenko, and E. L. Gavrilenko**

UDC 621.316

*The influence of the parameters of posistor elements and the conditions of their heat exchange on the electrical and dynamic characteristics of a posistor block has been investigated. Good agreement between calculation results and experimental data has been established.*

Thermoresistive elements with a positive temperature coefficient of resistance, i.e., posistors, are widely used in telecommunications equipment, instrumentation, control units, and many other types of electronic equipment. The principle of their operation is based on the property of increasing sharply their resistance (up to $10^7$ times) in the region of the phase-transition temperature $T_C$ (Curie point) under the action of a current or the environment and of restoring automatically the initial resistance upon elimination of the indicated causes. The basic principles of operation of posistors and means for calculating circuits involving them have been considered in many works [1, 2]. One factor limiting, in some cases, the efficiency of posistors is the presence of a varistor effect in them, i.e., a decrease in the jump of the resistance ($\gamma = R_{max}/R_{min}$) and the positive temperature coefficient of resistance ($\alpha = d \ln R/dT$) in the case of heating of the posistor by the current traversing it. In recent years, there has been a stable tendency toward switching to electric circuits with several posistor elements which are in both electrical contact and thermal contact (posistor block), which enables one, in particular, to decrease the varistor effect and accordingly improve the output characteristics of the circuits. It becomes more difficult to calculate the electrical characteristics of such blocks (especially dynamic ones), since they are determined not only by the electrical parameters of posistors and their thermal coupling with the ambient medium but also by the degree of thermal coupling between the posistors themselves. In the present work, we investigate the influence of the parameters of posistor elements, in particular, the temperatures of transition to a high-resistance state, and of the conditions of heat exchange on the electrophysical and dynamic characteristics of a posistor block that is widely used in electronics, in particular, in the demagnetization circuits of color kinescopes. The schematic diagram of such a device has the form shown in Fig. 1.

Structurally, the posistor block consists of a heating posistor ($R_2$) acting as a heating element and a controlling posistor ($R_1$) exerting direct control of the process of decay of the current in a demagnetization coil ($L$); the posistors are placed in a ceramic case. The posistor elements are in close thermal contact, and the condition $R_1 << R_2$, where $R_1$ corresponds to the resistance of the controlling posistor and $R_2$ corresponds to the resistance of the heating posistor, is satisfied at room temperature. The dynamics of operation of the indicated system was analyzed based on the model with lumped parameters under the assumption of uniformity of the temperature fields of the two posistors and the case and the absence of heat capacities in the insulation and of local couplings [3]. Such a model is described by the following system of equations:

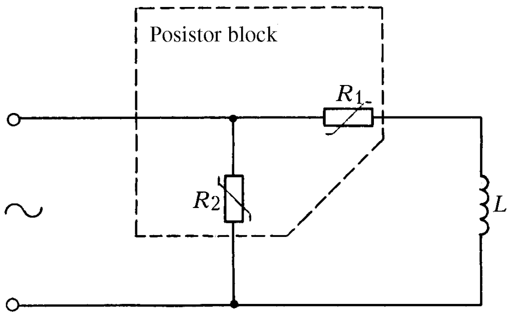
for the controlling posistor

$$C_1 dT_1/d\tau = P_1 - \sigma_{12} (T_1 - T_2) - \sigma_{13} (T_1 - T_3) , \qquad (1)$$

for the heating posistor

$$C_2 dT_2/d\tau = P_2 - \sigma_{12} (T_2 - T_1) - \sigma_{23} (T_2 - T_3) , \qquad (2)$$

Institute of Engineering Acoustics, National Academy of Sciences of Belarus, Vitebsk, Belarus; email: shut@vitebsk.by. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 75, No. 5, pp. 182–185, September–October, 2002. Original article submitted January 5, 2002.



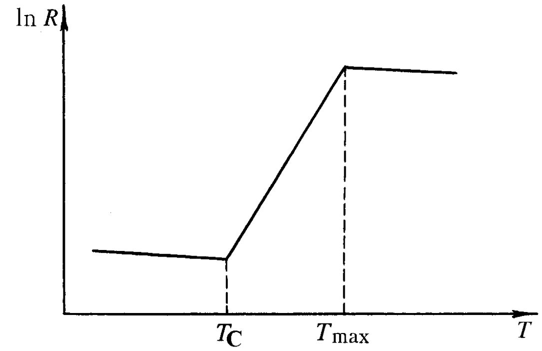
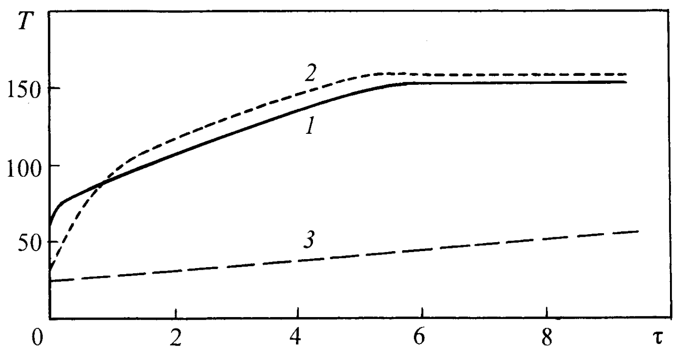




Fig. 1. Diagram of the device for demagnetization of color kinescopes.

Fig. 2. Generalized temperature characteristic of the posistors.



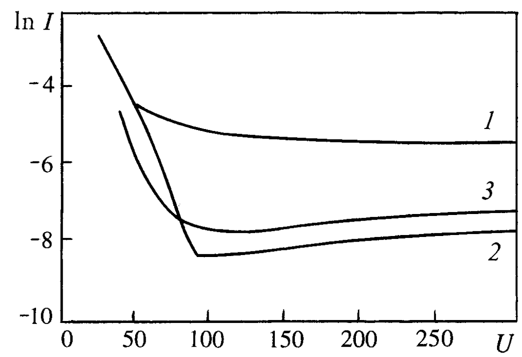




Fig. 3. Temperature of the constituent elements of the block vs. time: 1) controlling posistor ($T_{C1} \approx 50^{o}C$); 2) heating posistor ($T_{C2} \approx 50^{o}C$); 3) case. $C_1$ = $C_2$ = 1 J/K; $C_3$ = 5 J/K; $\sigma_{12}$ = 2 W/K; $\sigma_{13} = \sigma_{23}$ = 0.1 W/K; $\sigma_3$ = 0.1 W/K.

Fig. 4. Static volt-ampere characteristic of the posistor block: 1) $\Delta T_C$ = 50, 2) 100, and 3) $100^{o}C$ (experiment).

for the case

$$C_3 dT_3/d\tau = -\sigma_{13}(T_3 - T_1) - \sigma_{23}(T_3 - T_2) - \sigma_3(T_3 - T_0) \tag{3}$$

with the initial conditions $T_1 = T_2 = T_3 = T_0 = 20^{o}C$.

The powers released in the posistors when the a.c. voltage $U = U_0 \sin \omega t$ is applied to the system are considered to be uniformly distributed in volumes and to depend on their resistances (and accordingly on the temperature), and are determined by the expressions

$$P_1 = U^2/R_1(\tau)\,, \quad P_2 = U^2/R_2(\tau)\,.$$

In representing the heat-balance equation, we take into account the heat exchange between the posistors ($\sigma_{12}$), between the posistors and the case ($\sigma_{13}$, $\sigma_{23}$), and between the case and the environment ($\sigma_3$). To solve the system of equations (1)–(3) it is necessary to specify the temperature dependence of the resistances of the posistors. In the general case, it is rather complex in character and it is difficult to approximate by a single mathematical expression throughout the interval of operating temperatures. For the two posistors we employed a generalized, or "typed," temperature characteristic [2] (Fig. 2), which is distinguished for its simplicity and gives a correct idea of the general form of the curve. For this characteristic the resistance varies as $R = R_0 \exp[\alpha(T - T_C)]$ in the temperature range $T_C < T < T_{max}$ of practical importance.

The time dependence of the temperature of the constituent elements of the block upon applying voltage to it is presented in Fig. 3 (the dependence has been obtained from solution of Eqs. (1)–(3)). It is seen that already after a

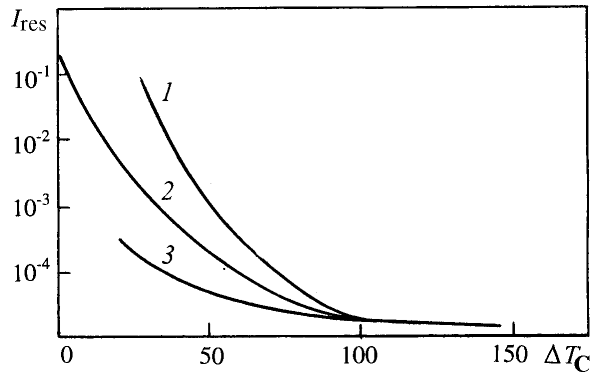



Fig. 5. Residual current vs. difference of the Curie temperatures of the posistors: 1) $\sigma_{13}$ = 0.1, 2) 0.05, and 3) 0.02 W/K.

time comparable to the period of variation (≈20 μsec) of the applied field the controlling posistor is heated to the temperature of transition to a high-resistance state ($T_{C1} \approx 50^oC$). The heating element acts as a heat-transferring radiator. After $\tau \approx 1$ sec, the temperatures of the posistors are equalized; thereafter the power of the heating element is consumed by heating the controlling posistor. After $\tau \approx 6$–8 sec, when the heating element attains a temperature of $T \approx T_{C2}$ the system passes to a state of heat equilibrium with a nearly $T_{C2}$ temperature. The temperature of the case in the final state is 30 to 40°C lower than the temperature of the posistors.

The calculated static volt-ampere characteristic of the controlling posistor (it characterizes the current $I$ traversing the posistor as a function of the applied voltage under steady-state heat equilibrium) for different values of the difference of the temperatures of transition of the heating and controlling posistors to a high-resistance state $\Delta T_C = T_{C2} - T_{C1}$ is shown in Fig. 4.

The most important characteristic of a posistor block determining its efficiency in electric circuits is the residual current $I_{res}$, i.e., the current traversing the controlling posistor upon the establishment of heat equilibrium in the system. The analysis made on the basis of solution of the system of equations (1)–(3) shows that the quantity $I_{res}$ depends on both the electrophysical characteristics of the constituent posistors of the block (resistance and $\Delta T_C$) and the conditions of heat exchange between the elements of the block (thermal conductivities $\sigma$). As is seen in Fig. 5, the residual current decreases with enhancement in the heat insulation of the posistors (i.e., with decrease in the thermal conductivities $\sigma_{13}$ and $\sigma_{23}$). The lowest value of $I_{res}$ is observed in the case where the temperature of transition of the heating posistor to a high-resistance state ($T_{C2}$) is in the vicinity of the temperature ($T_{max1}$) for the controlling posistor. When $T_{C1} > T_{max1}$ the influence of the heat-exchange conditions on the quantity $I_{res}$ can be disregarded. In practice, this means that the optimum characteristics of the system must be attained for a difference in the Curie temperatures of the posistor elements of $\Delta T_C \approx 100^oC$.

Figure 6a shows the curve of decay of the current traversing the controlling posistor; it is clear from the curve that the operating time $\tau_{op}$ (in which the amplitude of the current decreases twofold) is ≈50 μsec.

The technology for manufacturing ceramic posistor elements based on solid solutions of barium titanate ($BaTiO_3$) has been developed quite well at present [2]. It has been established that additions of lead (Pb) cause the temperature of the beginning of the region of the positive temperature coefficient of resistance to shift toward high temperatures (3.8°C/% (atomic)) while additions of strontium (Sr) cause $T_C$ to decrease (2.5°C/% (atomic)). As has been noted above, the optimum difference of the transition temperatures of the heating and controlling elements must be $\Delta T_C \approx 100^oC$. We employed the variant with transition temperatures of the posistors of $T_{C1} \approx 50^oC$ and $T_{C2} \approx 150^oC$. As the basic compositions for the posistor elements we selected the following percentage;

$(Ba_{0.7322}Sr_{0.2600}Y_{0.0073}) Ti_{1.0025}O_3$ + 0.24% Mn + 2.8% $SiO_2$ for the controlling posistor

and

$(Ba_{0.8422}\ Ca_{0.0800}\ Pb_{0.0700}\ Y_{0.0072}) Ti_{1.0020}O_3$ + 0.0125% Mn + 2.5% $SiO_2$ + 1% PbO for the heating posistor. The figures in the subscripts of the chemical elements denote the mole composition of the ceramic.

The amount of Mn and Y in both cases was selected from the requirement of the maximum values of the resistance jump ($\gamma = R_{max}/R_{min}$) and the breakdown voltage and the minimum values of the specific resistance for the

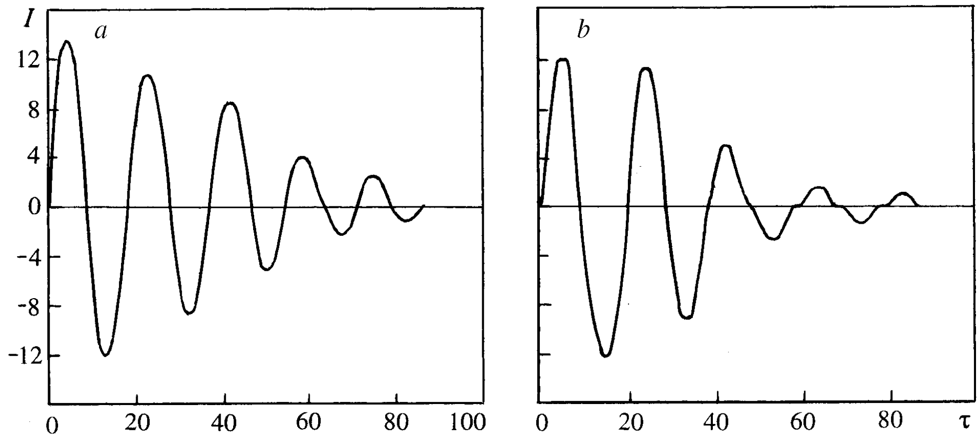


Fig. 6. Current vs. time: a) calculation; b) experiment. $I$, A; $\tau$, msec.

controlling posistor. The starting components had a purity of no lower than 99.5%. To manufacture the controlling element we used the traditional carbonate technology; the annealing was carried out in the regime

$$25 \xrightarrow{400\text{ min}} 200 \xrightarrow{100\text{ min}} 600 \xrightarrow{400\text{ min}} 1150 \xrightarrow{12\text{ min}} 1325 \xrightarrow{180\text{ min}} 900 \xrightarrow[\text{cooling}]{\text{natural}} 25^{\circ}\text{C}.$$

The samples produced had the following characteristics:

$$T_C = 50^{\circ}\text{C}, \quad R_{(25^{\circ}\text{C})} = 20\ \Omega, \quad \alpha \approx 15\%\ (^{\circ}\text{C})^{-1}, \quad \gamma = 10^5.$$

To manufacture the heating element we used the oxalate technology. The annealing was carried out in the regime

$$25 \xrightarrow{400\text{ min}} 200 \xrightarrow{100\text{ min}} 600 \xrightarrow{400\text{ min}} 1150 \xrightarrow{280\text{ min}}$$

$$1260 \xrightarrow{12\text{ min}} 1260 \xrightarrow{180\text{ min}} 900 \xrightarrow[\text{cooling}]{\text{natural}} 25^{\circ}\text{C}.$$

The excess of lead in the form of PbO was introduced as part of the ceramic to compensate for the lead evaporating in the process of annealing. The samples had the following characteristics:

$$T_C = 150^{\circ}\text{C}, \quad R_{(25^{\circ}\text{C})} = 1\ \Omega, \quad \alpha \approx 15\%\ (^{\circ}\text{C})^{-1}, \quad \gamma = 10^4.$$

Samples of both types had similar geometric dimensions: ∅ = 10 mm and $d$ = 2 mm. The electrodes were applied by brazing silver pastes of special composition.

The resistance, the reference points of the volt-ampere characteristics, and the temperature characteristics of the posistor block were determined in accordance with recommendations of the International Electrotechnical Committee on the equipment that meets the requirements for such measurements.

The results of investigating the static volt-ampere characteristic (curve 3 in Fig. 4) and the dynamic characteristics (Fig. 6b) of the manufactured posistor blocks are in good agreement with the calculated characteristics.

Thus, the results of calculating the thermal regime of operation of the posistor block which are based on solution of the system of equations (1)–(3) give a good agreement with experiment. The additional analysis has shown that a more complete description of the processes occurring in the system (due, for example, to a more accurate approximation of the dependence $R$ ($T$), to allowance for the difference between the volume-mean and surface temperatures of the posistors, etc.), making the calculations much more difficult, changes the results obtained only slightly.

## NOTATION

$T$, temperature, $^{o}$C; $T_{Ci}$, temperature of transition of the posistor, $^{o}$C; $T_{max}$ and $T_{min}$, maximum and minimum posistor temperatures, $^{o}$C; $\gamma$, resistance jump; $\alpha$, positive temperature coefficient of resistance, 1/$^{o}$C; $C_i$, heat capacity, J/(kg$^{o}$C); $P_i$, power released in the posistor, W; $U$, voltage, V; $\omega$, angular frequency, rad/sec; $R_i$, resistance of the element, $\Omega$; $\sigma_{ij}$, thermal conductivity, W/K; $\Delta T_C = T_{C2} - T_{C1}$, difference of the transition temperatures of the elements, $^{o}$C; $I$, current in the circuit, A; $I_{res}$, residual current in the circuit, A; $\tau$, time, sec; $\tau_{op}$, operating time of the block, sec; $\varnothing$; diameter of the samples, m; $d$, thickness of the samples, m; $L$, inductance of the demagnetization coil, mH. Subscripts: max, maximum; min, minimum; res, residual; op, operation; $i$, denotes, respectively, the controlling posistor ($i$ = 1), the heating posistor ($i$ = 2), and the case ($i$ = 3).

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