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POSISTOR BLOCKS OF PROTECTION OF AUTOMATIC TELEPHONE EXCHANGES

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The thermal and electrical parameters of posistor blocks or protection of automatic telephone exchanges have been investigated. A mathematical model making it possible to optimize the posistor parameters for designing protective blocks with required characteristics has been proposed.

Communications systems experience, in operation, electromagnetic disturbances, voltage surges, and current overloads from sources of industrial and natural origin. The disturbance and surge levels may exceed the stability levels at which the equipment used is rated, particularly in the case of digital automatic telephone exchanges, which are more sensitive to surges and current overloads than the old level step-by-step telephone exchanges. One factor presenting the most severe hazard is the supply-line voltage arriving at the communications line. This is predominantly the case in joint and close installation of communications and power cables (fires, broken insulation), in incorrect convergences and intersections with power lines (in rural areas), and when defective and uncertified units with a power supply of 220 V are used [1–3].

To protect automatic telephone exchanges against surges one mainly uses lightning arresters and varistors. Protection against current overloads is carried out using current-sensing elements, sharply increasing their resistance when the critical values of the current in the subscriber-line wires are exceeded. These can be ordinary fuses, thermocoils, or automatically restoring modern elements, i.e., posistors (also known by the name PTC thermistors) and PolySwitch elements [1]. Posistors with a positive temperature coefficient of resistance (PTC) based on barium-titanate semiconducting ceramics are the most promising current-protection elements [4]. This is due to the high PTC value and to the possibility of varying the switching temperature and the resistance of samples within wide limits. High breakdown voltages and stability of the characteristics are the advantages of posistors [5].

A current-protection element is integrated directly into the subscriber line, which imposes a constraint on the resistance of the element (no higher than 50 Ω). Considerable temperature gradients are formed in a low-resistance ceramics when the line voltage arrives at a line protected by a PTC thermistor. The high temperature differences result in substantial temperature stresses, which are responsible for the delamination fracture of posistors [6, 7]. The delamination mechanism is particularly pronounced in the case where discrete soldered posistor elements based on low-resistance ceramics are used. Realization of a block modification of current protection makes it possible to diminish the temperature stresses and accordingly to improve the reliability of protective elements by replacing the soldered contacts by pressed ones. Furthermore, when posistor blocks are used, one can easily realize the function of emergency indication of the line, employing a supplementary posistor sensor.

The present work seeks to investigate the influence of the parameters of posistor elements and the heat-exchange conditions on the electrophysical and dynamic characteristics of posistor blocks used in the circuits of current protection of automatic telephone exchanges.

Selection of the Optimum Parameters of Protective Posistors. A schematic diagram of a posistor device of protection of an automatic telephone exchange is shown in Fig. 1.

Structurally, the posistor block consists of encased posistors of protection of the line and a posistor sensor. The posistor elements are in thermal contact. Two constraints are imposed on the switching temperature T_C of the

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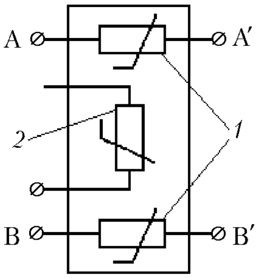


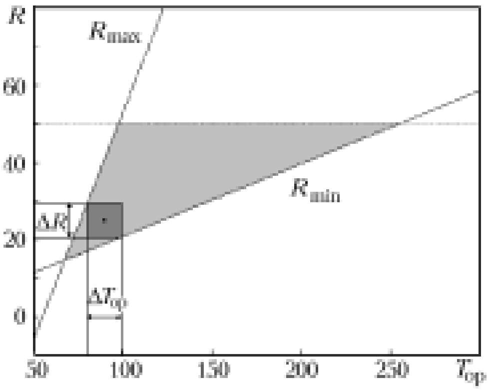


Fig. 1. Schematic diagram of the current protection of an automatic telephone exchange: A and B) linear (subscriber's) part; A′ and B′) exchange part; 1) protective posistors; 2) posistor sensor.

Fig. 2. Domain of permissible parameters (Curie temperature and resistance) of protective posistors.

posistor sensor. On the one hand, it must be lower than the switching temperature of the protective posistor, which makes it possible to reduce the operate time of emergency indication; on the other hand, it must be higher than the operating temperature of the protective element (for $I = I_n$) to exclude false operation.

The operating principle is as follows: when a line voltage of 220 V arrives at the communications line, a surge protection is switched on between the current protection and the input of the automatic telephone exchange; this protection connects the input of the automatic telephone exchange to earth. A large traversing current warms up the posistor, which in turn leads to a considerable growth in its resistance, thus restricting the current traversing the communications line.

The following basic specifications for protective blocks of automatic telephone exchanges with an operating current of 100 mA are placed as far as the electrical parameters are concerned: a) nonoperate current $I_n = 100$ mA, b) operate current $I_{op} = 2.5\ I_n = 250$ mA, c) operate time no longer than 120 sec for I_{op}, d) operate time no longer than 100 msec for $U = 220$ V, e) maximum resistance no more than 50 Ω, and f) ambient temperature from −10 to +55°C.

The appropriate selection of the characteristics of posistors (resistance, switching temperature) is necessary for realizing blocks with the above specifications. The optimum selection of the posistor parameters can be made on the basis of the heat-balance equation

$$P = \sigma\,(T - T_0)\,. \tag{1}$$

Then the nonoperate condition at the maximum ambient temperature is

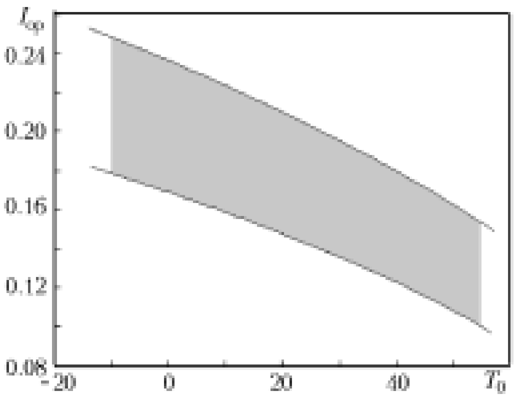
$$R < R_{\max} = \sigma\,(T_C - T_{0\max})/I_n^2\,, \tag{2}$$

the operate condition at the minimum ambient temperature is

$$R > R_{\min} = \sigma\,(T_C - T_{0\min})/I_{op}^2\,. \tag{3}$$

The domain of permissible values of the resistances and the Curie temperatures that satisfies the specifications is given in Fig. 2.

The elements of choice for increasing the speed of response of the protection are those with the lowest value of the Curie temperature. At the same time, in commercial production of posistors, we have a spread in their characteristics, including the resistance and the switching temperature. On this basis, the permissible spread in thermistor parameters may not be beyond the domain of permissible values of the resistances and the Curie temperature (rectangular



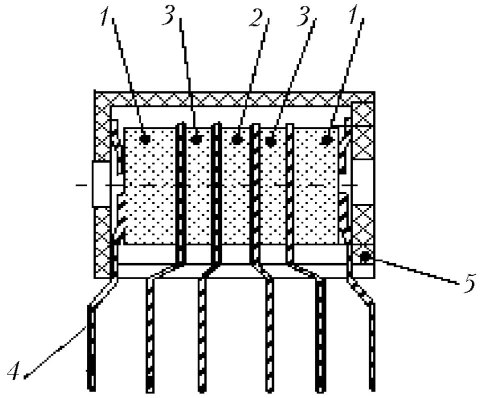


Fig. 3. Operate current vs. ambient temperature (with allowance for the spread in posistor parameters (Curie temperature and resistance)).

Fig. 4. Block of protection of an automatic telephone exchange: 1) protective posistors; 2) posistor sensor; 3) electric insulation disks; 4) contacts; 5) casing of the block.

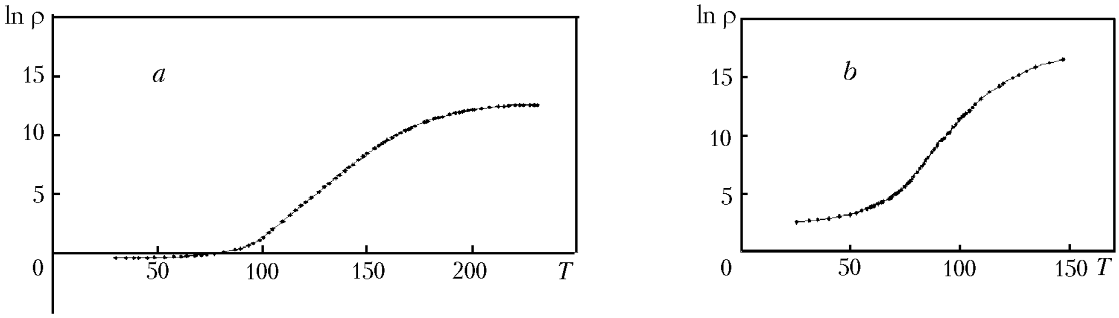


Fig. 5. Specific resistance of the protection posistor (a) and the posistor sensor (b) vs. temperature.

TABLE 1. Characteristics of Posistor Elements

Posistor	T_C	ρ_{25}	α	R_{max}/R_{min}	E_{br}
Sensor	70	8	19	$1.2 \cdot 10^6$	255
Protective element	90	0.4	14	$3 \cdot 10^5$	240

domain in Fig. 2). The resistance of the protective element can have values $R = 25.0\ \Omega \pm 17\%$ for the Curie temperatures $T_C = 90 \pm 10^oC$ and $R = 27.5\ \Omega \pm 28\%$ for $T_C = 90 \pm 5^oC$. The values of the operate currents as functions of the ambient temperature for posistors with $T_C = 90 \pm 5^oC$ and $R = 27.5\ \Omega \pm 28\%$ are given in Fig. 3; it is seen in the figure that the minimum operate current is 250 mA, whereas the maximum nonoperate current is 100 mA. In accordance with a number of the ratings of E24 resistances and the recommendations given above, it is expedient to use thermoresistors with $T_C = 90^oC$ and $R = 27\ \Omega$ as protective elements.

Block of Protection of an Automatic Telephone Exchange. A diagram of assembly of the posistor block is given in Fig. 4. The casing of the protection block of an automatic telephone exchange is manufactured from plastic (with a fusion temperature no lower than 180^oC) by casting; the electric insulation disks are manufactured from a ceramic dielectric (ultraporcelain) with an insulation resistance no lower than 1000 V/mm. Beryllium bronze or stainless steel were used to manufacture leading-out contacts. To manufacture posistor elements we developed materials of the following compositions: $Ba_{0.8875}Sr_{0.1050}\ Y_{0.0075}Ti_{1.0025}O_3$ + 0.125% Mn + 2.5% SiO_2 for the protection posistor and $Ba_{0.8175}Sr_{0.1750}Y_{0.0075}Ti_{1.0025}O_3$ + 0.125% Mn + 2.5% SiO_2 for the posistor sensor.

The technology of manufacture of the posistor material has been given in [4]. The resulting samples of protection posistors had a diameter of 5 mm and a thickness of 1.6 mm; the posistor sensor had a diameter of 5 mm and a thickness of 1.1 mm. The dependences of the specific resistance of the protection posistor and the posistor sensor on temperature are shown in Fig. 5. Table 1 gives their basic characteristics.

Analysis of the Operation of the Block. As has already been noted, the line voltage arriving at the communications line may cause considerable damage to the equipment of digital exchanges. Therefore, it is of particular interest to consider the efficiency of operation of a posistor block for the case where a voltage of 220 V occurs in the line.

The operation of the protection device can be analyzed based on the lumped-parameter model under the assumption that the temperature fields of all the posistors and the casing are uniform and there are no heat capacities in the insulation and local couplings [8, 9]. Such a model is described by the following system of equations:

for the first protection posistor ($i = 1$)

$$C_1 dT_1/dt = P_1 - \sigma_{14}(T_1 - T_4) - \sigma_{13}(T_1 - T_3)\,, \tag{4}$$

for the second posistor ($i = 2$)

$$C_2 dT_2/dt = P_2 - \sigma_{24}(T_2 - T_4) - \sigma_{23}(T_2 - T_3)\,, \tag{5}$$

for the casing ($i = 3$)

$$C_3 dT_3/dt = -\sigma_{13}(T_3 - T_1) - \sigma_{23}(T_3 - T_2) - \sigma_{43}(T_3 - T_4) - \sigma_3(T_3 - T_0)\,, \tag{6}$$

for the posistor sensor ($i = 4$)

$$C_4 dT_4/dt = -\sigma_{41}(T_4 - T_1) - \sigma_{42}(T_4 - T_2) - \sigma_{13}(T_1 - T_3) \tag{7}$$

with the initial conditions $T_1 = T_2 = T_3 = T_4 = T_0 = 25^{\circ}$C.

The power released in the posistors in application of the voltage U is assumed to be uniformly distributed throughout the volume and is determined as $P_i = U_i^2/R_i\ (T_i)$, $i = 1$ and 2. In writing the heat-balance equation, we allowed for the heat exchange between the protection posistors and the sensor ($\sigma_{14} = \sigma_{41}$ and $\sigma_{24} = \sigma_{42}$), all the posistors and the casing ($\sigma_{13} = \sigma_{31}$, $\sigma_{23} = \sigma_{32}$, and $\sigma_{43} = \sigma_{34}$), and between the casing and the ambient medium (σ_3).

To solve the system of equations (4)–(7) we must also prescribe the temperature dependence of the resistances of the posistors. For all the posistors, we used a generalized, or "typed," temperature characteristic [4], which is noted for its simplicity and gives you a correct idea of the general form of the curve:

$$R(T) = \begin{cases} R_0\,, & T < T_C\,; \\ R_0 \exp\left\{\alpha (T - T_C)\right\}, & T_C \le T < T_{\max}\,; \\ R_0 \exp\left\{\alpha (T_{\max} - T_C)\right\}, & T > T_{\max}\,. \end{cases} \tag{8}$$

It is impossible to accurately calculate the coefficients of heat exchange between the elements in the block (σ_{ij}) and the ambient medium (σ_3) quantitatively; they can be evaluated from experimental data. We obtained the following values of the heat-exchange coefficients:

$$\sigma_3 = 0.026\ \text{W/K}\,,\ \sigma_{13} = \sigma_{23} = 0.0125\ \text{W/K}\,,\ \sigma_{43} = 0.0056\ \text{W/K}\,,\ \sigma_{14} = \sigma_{24} = 0.025\ \text{W/K}\,.$$

The calculated temperatures of the elements of the posistor block when a voltage of 220 V is applied to one protective thermoresistor are given in Fig. 6. This figure gives experimental data on the change in the temperature of

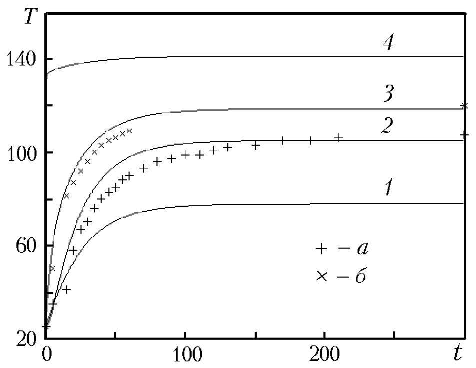


Fig. 6. Change in the temperature of the posistor-block elements: 1) casing; 2) disconnected protection posistor; 3) posistor sensor; 4) connected protection posistor (calculation); a) temperature of the disconnected protection posistor; 6) temperature of the posistor sensor (experiment).

the posistor sensor and a disconnected protective element. It is seen that the theoretical and experimental results are in good agreement.

The operate time of the protective element does not exceed 20 msec (in application of 220 V). The residual current in the circuit was 6 ± 0.5 mA (calculated value of 6.2 mA).

The change in the resistance of the posistor sensor when the line voltage arrives at the communications line is shown in Fig. 6. The operate time in which the resistance attains its value of $R = 1000\ R_{25}$ is 45 sec.

Posistor protection blocks withstand no less than 1000 switching-on cycles (with 220 V) without degrading the electrophysical parameters of the elements. At the same time, the analogous parameter for soldered discrete elements is about 10–100 cycles.

The approaches described above make it possible to carry out optimization of the thermistor parameters with a degree of accuracy sufficient for designing protective blocks of automatic telephone exchanges with a wide range of operating currents (30–200 mA).

Thus, the mathematical model proposed makes it possible to optimize the parameters of PTC thermistors for designing posistor blocks intended for current protection of automatic telephone exchanges with required characteristics. In the work, we have described the thermal and electrical parameters of posistor blocks of protection of an automatic telephone exchange with an operating current of 100 mA. It has been shown that protective devices in a block modification are more efficient and reliable than discrete elements.

NOTATION

C, heat capacity per unit volume, J/(m^3·K); E_{br}, breakdown strength of the electric field, V/mm; I, current, A; I_n and I_{op}, nonoperate and operate currents, A; P, power released in the posistor, W; R, resistance of the posistor, Ω; R_{25}, resistance of the posistor at 25^{o}C, Ω; R_{max} and R_{min}, maximum and minimum resistances, Ω; t, time, sec; T, average temperature of the posistor, ^{o}C; T_C, Curie temperature, ^{o}C; T_{max}, maximum temperature of the posistor, ^{o}C; T_{0max} and T_{0min}, maximum and minimum ambient temperatures, ^{o}C; U, voltage applied to the posistor, V; α, temperature coefficient of resistance, %/K; ρ, specific resistance, Ω·m; ρ_{25}, specific resistance at 25^{o}C, Ω·m; σ, heat-exchange coefficient, W/K; σ_{ij}, coefficient of heat exchange between the ith and jth elements, W/K; δ_3, coefficient of heat exchange between the casing and the ambient medium, W/K. Subscripts: max, maximum; min, minimum; n, nonoperation; br, breakdown; op, operation; 0, ambient medium; 1 and 2, first and second protective posistors; 3, casing; 4, posistor sensor.

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