DETERMINATION OF THE HEAT CAPACITY OF POSISTORS

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A method is proposed for determining the heat capacity of posistors. The temperature dependence of the heat capacity is considered.

In analyzing the transient processes in electrical circuits containing posistors, it is necessary to know the heat capacity of the latter. So far, however, nothing has been published on this subject.

This paper describes a method of determining the heat capacity of posistors and investigates the temperature dependence of that quantity.

Several methods have been proposed for determining the heat capacity of thermistors with a negative temperature coefficient. Basically, these methods reduced to the analysis of the transient process in a circuit composed of a thermistor and a linear resistance [1, 2]. Obviously, a similar method can also be used to determine the heat capacity of posistors. The only difference is that in this case it is more convenient to analyze the transient process in a circuit consisting only of a posistor (without a series resistance) connected to a constant-voltage source. Otherwise the transient processes are seriously complicated owing to the presence of a varistor effect, i.e., a dependence of posistor resistance on applied voltage. As will be shown below, the proposed approach considerably simplifies the calculations.

The heat capacity of the posistor c_p was determined from the heat balance equation

$$P = k(\theta - \theta_0) + c_p \frac{d\theta}{dt} \tag{1}$$

on the basis of oscillograms of the transient process $I = f(t)$ with the posistor connected to a constant-voltage source at θ_0 = const. The term $d\theta/dt \approx \Delta\theta/\Delta t$ is determined by graphic differentiation of the function $\theta = f(t)$. This relation can be reconstructed from the $I = f(t)$ oscillogram at U = const as follows.

The posistor resistance due to the simultaneous action of the thermal and varistor effects is given by the expression

$$R_p(\theta, U) = R_{p1}(\theta) \exp[-b(\theta)(\sqrt{U} - 1)]. \tag{2}$$

Taking logs, we obtain

$$\ln R_p(\theta, U) = \ln R_{p1}(\theta) - b(\theta)(\sqrt{U} - 1). \tag{3}$$

The term $R_{p1}(\theta)$ is the temperature characteristic of the posistor recorded at a voltage of 1 V. The relation $b(\theta)$ resembles the temperature characteristic of the posistor and can be obtained as follows. At a certain temperature of the ambient medium θ_0 we record on the oscillograph the transient process $I = f(t)$ with the posistor connected to a constant-voltage source. Obviously, at the initial instant, at t = 0, the current is determined by the temperature of the ambient medium (since as a result of inertia the temperature of the posistor cannot change instantaneously) and the voltage supplied.

In accordance with equation (3), in this case

$$b = \frac{\ln R_{p1}(\theta) - \ln \dfrac{U}{I_{t=0}}}{\sqrt{U} - 1} = f(\theta). \tag{4}$$

Remark. For voltages not exceeding 1 V and with a certain degree of approximation for temperatures not exceeding 126–127° C (Curie point) it is possible to use the following expression for calculating b:

$$R_p(\theta,\ U) = R_{p0}(\theta)\exp\left[-b(\theta)\sqrt{U}\right], \tag{2'}$$

then

$$b = \frac{\ln R_{p0}(\theta) - \ln \dfrac{U}{I_{t=0}}}{\sqrt{U}} = f(\theta). \tag{4'}$$

Here, $R_{p0}(\theta)$ is the temperature characteristic of the posistor recorded at $P_\alpha \approx 0$ (see Fig. 1).

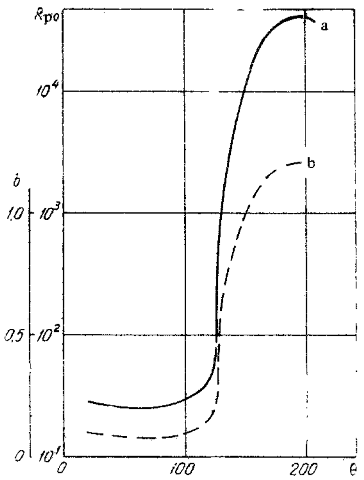

Fig. 1. Temperature characteristic of posistor with R_{20} = 30 ohms (R is ohms, θ in °C) and nonlinearity factor b (volt$^{-1/2}$) as a function of posistor temperature θ (°C).

Thus, it is possible to determine the nonlinearity factor b at different temperatures of the ambient medium and construct the b $f(\theta)$ relation (see Fig. 1).

By assigning different values of the posistor temperature θ, using the available relations $R_{pi}(\theta)$ and $b(\theta)$, we can easily determine $R_p(\theta, U)$ from expression (3) at constant posistor voltage. In this way we can construct a family of $I = f(\theta)$ curves at U = const as parameter. Having the relations $I = f(t)$ and $I = f(\theta)$, we can easily construct the curve expressing the variation of temperature with time $\theta = f(t)$ when the posistor is connected to a constant voltage.

An analysis of the experimental data showed that the heat capacity of the posistor c_p is not a constant quantity. It depends strongly on the temperature of the posistor and the temperature of the ambient medium.

The relation $c_p = f(\theta)$ can be constructed as follows. For small finite temperature increments the heat balance equation can be represented in the form:

$$\frac{UI_n(t_n) - k(\theta_n - \theta_0)}{c_p} \approx \frac{\Delta\theta_n}{\Delta t_n}. \tag{5}$$

On the graphs of $I = f(t)$ and $\theta = f(t)$ a series of straight lines parallel to the ordinate axis are drawn at time intervals Δt_p, a linear dependence of the current and temperature on time being assumed in each interval (see Fig. 2). Then the data obtained are substituted in (5). In this way we determine the heat capacity for each interval and from the data obtained construct the relation $c_p = f(\theta)$. The curve in Fig. 3 represents the $c_p = f(\theta)$ calculated by the method described above for ST 5-1 posistors with a resistance R_{20} = 30 ohms. The curves for other posistors are similar.

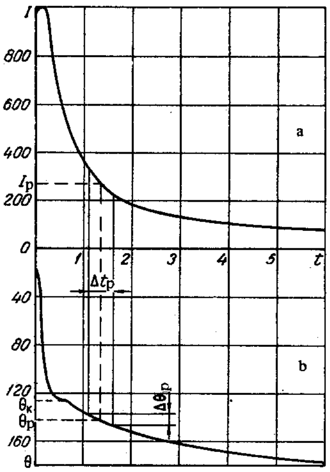

Fig. 2. Oscillogram of the transient process I $=f$(t) (I in mA; t in sec) and posistor temperature θ (°C) as a function of the time of the transient process t (sec). The graphs correspond to a posistor with R_{20} = = 30 ohms.

A knowledge of the relation $c_p = f(\theta)$ is necessary for the correct calculation of the dynamic characteristics of posistor circuits. After analyzing this relation it is possible to draw the following conclusions. In the range of posistor temperatures 20–110° C at θ_0 = const it may be assumed that the heat capacity does not depend on posistor temperature (see Fig. 3). There then follows a sharp change in heat capacity and the experimental curves have a characteristic spike, the sharp maximum corresponding to the Curie temperature, which for the posistors investigated is observed in the region 126.5–127° C. This effect is associated with the specific character of the phase transformation experienced by semiconducting barium titanate in the neighborhood of the Curie point. It is known that the appearance of additional degrees of freedom, changes in the state of aggregation, and changes in the law of dispersion or the frequency spectrum of the system lead to a change in the heat capacity and its temperature dependence. Accordingly, heat capacity measurements serve as a method of studying phase transformations. The jump in heat capacity is attributable to the fact that near the Curie point the structure of semiconducting barium titanate passes from the tetragonal to the cubic phase. At the maximum the heat capacity reaches 1.88 W · sec/deg for a posistor with R_{20} = 30 ohms and 1.3 W · sec/deg for a posistor with R_{20} = 96 ohms, i. e., the heat capacity increases by a factor of 15–20 as compared with that at posistor temperatures in the range 20–100° C. With further increase in posistor temperature the heat capacity falls sharply. In the range 130–190° C the heat capacity of the posistor may again be assumed constant.

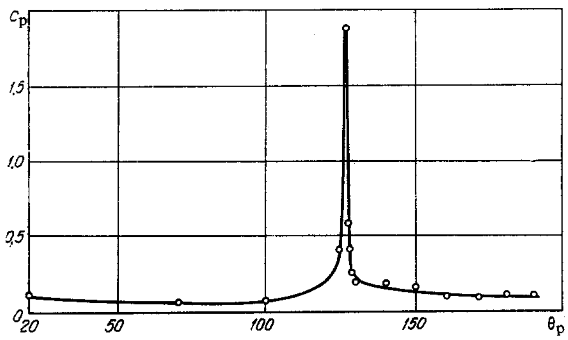

Fig. 3. Heat capacity of posistor c_p (W · sec/deg) as a function of its temperature θ_p (°C) for a posistor with R_{20} = 30 ohms.

The results of the experiments showed that the heat capacity of a posistor also depends on the temperature of the ambient medium, decreasing as the latter increases. In the range 20–70° C the heat capacity is almost independent of the temperature of the ambient medium. However, with further increase in ambient temperature this dependence becomes even more explicit. The heat capacity decreases especially sharply at ambient temperatures close to the Curie point (comparison of heat capacities at constant posistor temperature and various ambient temperatures). Comparing the heat capacities at the Curie point at $\theta_0 = 20°$ C and $\theta_0 = 125°$ C, we find that in the latter case the spike is considerably more smoothed.

The results obtained can be used in the investigation of transient processes in posistor circuits and also in various thermal studies.

NOTATION

c_p—heat capacity of posistor
θ—temperature of posistor, °C
θ_0—ambient temperature, °C
P—power supplied to the posistor
P_α—power dissipated by the posistor into the ambient medium
k—dissipation factor
b—nonlinearity factor of the posistor
U—voltage
I—current
t—time
R_{p0}—resistance of the posistor determined from its temperature characteristic
R_p—resistance of the posistor due to the combined action of thermal and varistor effects

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