DETERMINATION OF THE HEAT LOAD ON A THERMOELECTRIC ELEMENT

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We consider a method of determining the heat load on a thermoelectric element, based on the experimental current-voltage characteristic of the latter. The possibility of determining the efficiency parameters of the thermoelectric element is indicated; this is accomplished on the basis of the initial dynamic slope of the current-voltage characteristic.

The magnitude of the heat load on a thermoelectric element [thermocouple] is of particular importance in the design of thermoelectric thermostating devices. Analytical methods of determining this quantity are cumbersome and laborious. The proposed engineering method of determining the heat load is based on deriving an experimental current-voltage characteristic for a thermoelectric element within a thermoelectric device.

The current-voltage characteristic of a semiconductor thermoelectric element—which is understood to mean the voltage drop across the thermoelectric element as a function of the current passed through the element—can be presented in the form

$$U = IR + \alpha\Delta T = IR\left[1 + \frac{z}{\alpha}(\Pi - 0.5\,IR)\right] - \frac{z}{\alpha}RQ_0, \qquad (1)$$

where, according to the general theory of thermoelectric cooling [1]

$$\Delta T = \frac{1}{K}(I\Pi - 0.5I^2R - Q_0), \qquad (2)$$

and

$$K = \frac{\alpha^2}{Rz}. \qquad (3)$$

Analysis of formula (1) demonstrates that the current-voltage characteristic is a linear function of the heat load. Considering the absolute difference between the current-voltage characteristic for a specific heat load and the ideal current-voltage characteristic for a zero heat load (see the figure), we will obtain

$$\Delta U(0) = \frac{z}{\alpha}RQ_0, \qquad (4)$$

whence the magnitude of the heat load on the element is defined by the equation

$$Q_0 = \frac{\alpha}{Rz}\Delta U(0). \qquad (5)$$

If we know the basic parameters of the element, i.e., α, R, and z and the magnitude of the shift $\Delta U(0)$—determined from the experimental current-voltage characteristic—it is easy to find Q_0 from (5). The determination of the thermal emf and the ohmic resistance presents no difficulty.

The determination of the efficiency parameter is a complex engineering problem. The indirect method of determining the efficiency parameter for semiconductor thermoelectric elements (based on the determination of the ohmic resistance, the coefficients of the thermal emf, and the coefficient of the heat conduction between the junctions of the thermocouple) according to (3) involves a number of difficulties associated with the execution of precision thermal measurements required to determine the thermal conductivity of the element. The direct methods of determining the efficiency parameter (the Harman method and its modifications) involve measurements under special conditions which, if not met, result in substantial error. In the case under consideration it is convenient to employ the indirect method of determining the efficiency parameter from the initial dynamic slope of the current-voltage characteristic. Having defined the dynamic slope of the current-voltage characteristic as the first derivative of the voltage with respect to the current, we obtain

$$S_d = \frac{dU}{dI} = R\left(\frac{z}{\alpha}\Pi + 1\right) - \frac{z}{\alpha}R^2I. \qquad (6)$$

When I = 0, the initial dynamic slope is expressed by

$$S_0 = S_d(0) = R\left(\frac{z}{\alpha}\Pi + 1\right), \qquad (7)$$

whence

$$z = \frac{\alpha}{\Pi}\left(\frac{S_0}{R} - 1\right). \qquad (8)$$

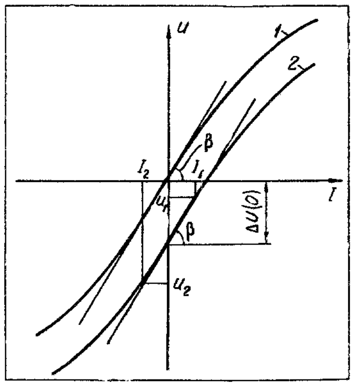
Bearing in mind that according to [1] $\Pi = \alpha T$, and assuming that the temperature of the working junction when I = 0 is equal to the temperature of the ambient medium, we find that the efficiency parameter for the element is given by

$$z = \frac{1}{T_{amb}}\left(\frac{S_0}{R} - 1\right). \qquad (9)$$

Analysis of (9) demonstrates that to find the efficiency parameter for the element we have to know the ohmic resistance of the element, the initial dynamic slope of its current-voltage characteristic, defined by the slope β of the tangent to the function $U = f(I)$ at point I = 0, in addition to knowing the temperature of the ambient medium at which R and S_0 were determined. The experimental characteristic differs from the theoretical by greater linearity over the entire working range, and the initial dynamic slope can be replaced by a static slope; moreover, the graphical methods can be replaced with analytical procedures. The advantages of the method are based on the replacement of the relatively complex heat measurements by simple and reliable electrical measurements, and on the fact that the effect of the heat losses has been eliminated because the dynamic slope of the current-voltage characteristic is independent of the heat load. This method makes it possible to determine the temperature relationship for the efficiency parameter; all of the measurements must be carried out in a thermostat in this case. The accuracy of the method is governed by the accuracy with which we determine R, S_0, and T_{amb}, and by the relative error in the temperature difference when determining R and S_0.

The practical application of this method to determine the heat load on the element is achieved when the power supply for the element is ensured and when we have determined the experimental relationship between the voltage U applied to the element and the current I which is passed through the element. Because $\Delta U(0)$ is constant over the entire current-voltage characteristic, in the determination of the characteristic we can limit ourselves exclusively to the segment in the vicinity of zero. The application of the method for the determination of the heat load therefore reduces to making it possible to determine the function $U = f(I)$ as a minimum at two points: in the positive (I_1) and the negative (I_2) directions of the current, and here it is convenient to assume that $|I_1| = |I_2|$. These voltage values define the initial dynamic slope and the magnitude of the shift in the current-voltage characteristic on the basis of $S_0 = (U_1 - U_2)/2I_1$ and $\Delta U(0) = (U_1 + U_2)/2$. To eliminate the nonlinearity of the current-voltage characteristic, we must see to it that the measurement current is smaller by an order of magnitude than the optimum current for the element.

The method was tested experimentally on a special device designed to test thermoelectric elements. The magnitude of the heat load on the element—calculated analytically—was compared with a quantity derived from (9) on low-current modular TBM-1-type thermocouples. The experimental results demonstrated that the relative error in the method of determining the magnitude of the heat load on the element—according



Current-voltage characteristic of thermocouple 1) $Q_0 = 0$; 2) $Q_0 > 0$.

to the method considered here—does not exceed 10%, which is completely acceptable for engineering plans in the design of thermoelectric devices.

NOTATION

U is the voltage drop across the thermocouple; I is the thermocouple current; R is the ohmic resistance; α is the coefficient of thermal electromotive force; z is the efficiency parameter; Π is the Peltier number; K is the heat conduction between thermocouple junctions; Q_0 is the heat load on the thermocouple; $\Delta U(0)$ is the initial shift of the current-voltage characteristic; S_0 is the initial dynamic slope of the current-voltage characteristic.

REFERENCE

1. A. F. Ioffe et al., Thermoelectric Cooling [in Russian], Izd. AN SSSR, Moscow-Leningrad, 1956.

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