AUTOMATIC DETERMINATION OF THE THERMAL DIFFUSIVITY OF HEAT INSULATORS

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This paper describes the construction, operating principle, and technical specifications of an automatic apparatus for determining the thermal diffusivity of heat insulators. The automatically determined temperature dependences of the thermal diffusivities of asbestos cement, textolite, micarta, and polystyrene are discussed.

The principle of mathematical simulation was used to solve the problem of automatic determination of thermal diffusivity. The design of the computer was based on a simulation formula [1] connecting the measured physical parameters—the heating temperature and the temperature drop on the investigated plates. These parameters, which vary continuously during the experiment, are converted to a direct voltage and fed into the computer.

The result of the computation—the thermal diffusivity—is obtained almost immediately after the input of the initial data and is recorded on graph tape of an electronic recorder.

This apparatus (Fig. 1) is free from the faults inherent to the apparatus in [1, 2], since it has an electronic computer. The determination of the thermal diffusivity in a wide temperature range entails three operations: differentiation, multiplication by a constant factor, and division.

The sensors for the initial values—the heating temperature t_h of the specimen and the temperature drop Δt on the specimen—consist of chromel-copel thermocouples T_2 and T_1, the latter being of the differential type. The thermo-emf of these thermocouples is converted to a proportional direct current by the electronic converters CC_1 and CC_2. The signal proportional to the temperature drop Δt is fed directly into the division circuit and the signal proportional to the heating temperature t_h of the external side faces of the specimen is first differentiated and then amplified by the converter CC_3.

The division circuit is based on a EPP-09 automatic millivoltmeter with a uniform scale. The circuit consists of a slide wire, connected up in a particular manner, and a servo system. Currents proportional to the derivative of the heating temperature with respect to the time $dt_h/d\tau$ and the temperature drop Δt are fed to the two inputs of the slide wire. The voltage applied to the input of the null indicator of the servo system from the slide wire is proportional to the difference

$$k_1 \frac{dt_h}{d\tau} - k_2 \Delta t.$$

The scale readings on the millivoltmeter are proportional to

$$n = 2 - I_1/I_2,$$

where n is the ratio of the pointer reading to the whole scale, I_1 is the output current of CC_3, which is proportional to $dt_h/d\tau$; I_2 is the output current, which is proportional to Δt.

Thus

$$n = 2 - k_1 \frac{dt_h}{d\tau} \Big/ k_2 \Delta t,$$

from which

$$\frac{dt_h}{d\tau} \Big/ \Delta t = \frac{k_2}{k_1} (2 - n).$$

The formula for calculating the thermal diffusivity has the form

$$a = (2 - n) l^2/43.6R, \tag{1}$$

where l is the thickness of the specimen plate in mm; R is the resistance (in ohm) in the differentiating circuit, which determines the range of measurement of the thermal diffusivity a. From this formula a is obtained in m^2/h.

It follows from expression (1) that a reduction in the thermal diffusivity corresponds to an increase in the scale reading of the instrument. The scale is calculated for each specific expression for the thickness of the specimen plate.

The apparatus can be used for automatic measurement of the thermal diffusivity of heat insulators in the range $0.6-5 \cdot 10^{-7}$ m^2/sec. This range is divided into three subranges. Changeover from one to the other is effected by switching the resistors in the differentiating circuit. The specimens consist of 100 × 100 mm plates, 3–10 mm thick. The contacting surfaces of the plates are polished for good thermal contact.

Quasi-stationary thermal conditions are produced in the plates by an automatic programmed regulating system in which the regulating device is a EP-T-59 electronic regulator [3]. The prescribed rate of heating is fixed by a programmed controller consisting of a device producing a linearly increasing voltage. The temperature sensor for the regulating system is a chromel-copel thermocouple T_3. By means of two RKN electromagnetic relays the regulator controls a reversible motor RM, which is connected through a reducing gear to the slider of an autotransformer. The latter alters the current through the heaters H_1 and H_2 so that the temperature on the outer faces of the specimens varies linearly.

The range of variation of the heating temperature is 20°–400° C. The upper limit can be increased to 600°–800° C; it depends on the design of the heaters and the electrical circuit of the current converters.

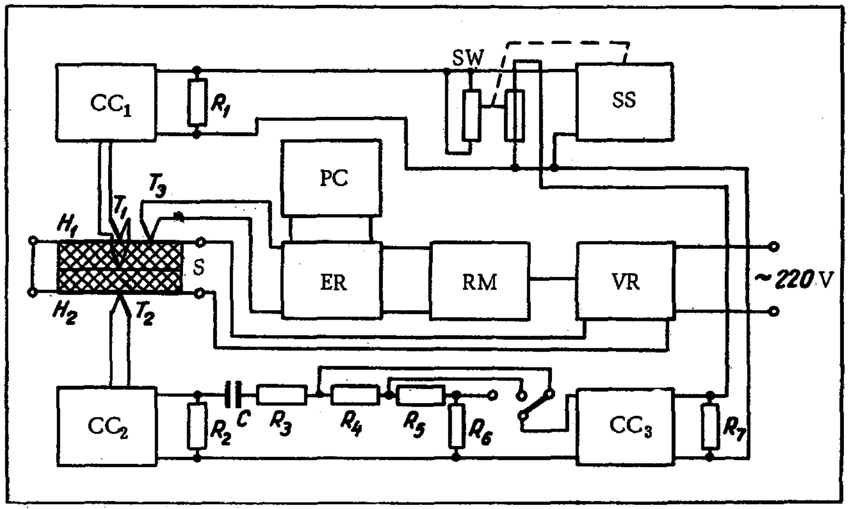

Fig. 1. Block diagram of apparatus. CC_1, CC_2, CC_3) Current converters; H_1, H_2) flat heaters; T_1) differential thermocouple; T_2, T_3) thermocouples; S) specimens; SS) servo system of electronic millivoltmeter; ER) electronic regulator; PC) programmed controller; RM) reversible motor with reducing gear; VR) voltage regulator; SW) slide wire of electronic millivoltmeter.

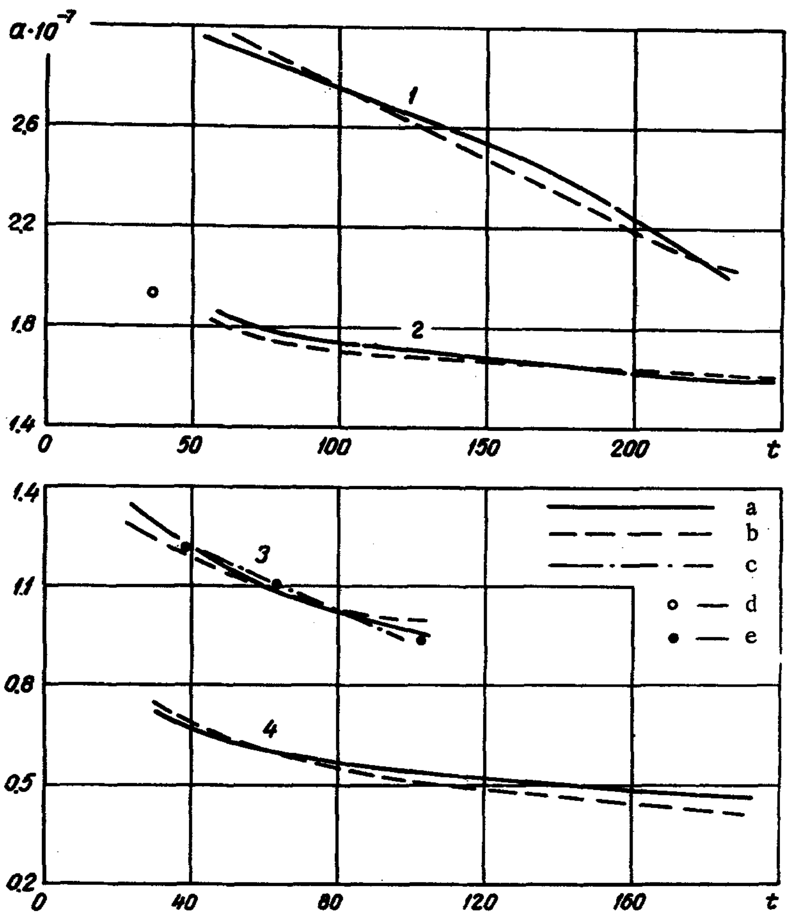

Fig. 2. Plots of thermal diffusivity a($m^2 \cdot sec^{-1}$) of textolite (1), asbestos cement (2), polystyrene (3), and micarta (4) against temperature t (°C): a) Determined by automatic device; b) by manual method; c) from data of [5]; d and e) from data of [6] and [4].

Figure 2 compares the data obtained on the automatic apparatus with data obtained manually by the quasi-stationary heat-regime method, and also with published data. An examination of the temperature dependences of the thermal diffusivity of heat insulators indicates a satisfactory agreement to a reasonable degree of accuracy. There is a systematic error of 1.7–2% due to the higher values given by the automatic device in the first stage of the experiment and the lower values in the second stage in comparison with the manually obtained results. We think that the automatically obtained results are the more accurate. The automatic device continuously follows the linearity of the thermogram. In the first stage of the experiment, despite the generally good linearity of the thermogram, there is a relatively small static regulation error. In this case the varying value of the temperature lags a little behind, and in the second stage is in advance of, the assigned temperature. In view of this, the derivative of the temperature with respect to time changes and so does the nature of the temperature dependence of the thermal diffusivity.

The obtained temperature dependences of the thermal diffusivity of heat insulators are curves which descend with temperature increase. Several of them are in good agreement with published values of a [4, 5].

We estimate the experimental error as follows:

1. The error due to the nonlinearity of heating of the specimen plates is 1.5–2%.

2. The error due to incomplete thermal contact between the heaters and plates is reduced to a minimum by the use of a specially designed pneumatic clamp, which produces a specific pressure of more than $196 \cdot 10^4$ N/m^2 on 100 × 100 mm plates, and of more than $764 \cdot 10^4$ N/m^2 on 50 × 50 mm plates. Moreover, since the plates are polished and the thermocouples are flattened this error obviously cannot be more than 1.5–2%.

3. The error due to nonlinearity of conversion of the measured thermo-emf to direct current at the output of the current converters is not more than 0.5%. The linearity of the amplitude characteristics of the current converters ensures an error of about 0.1–0.2%.

4. The error due to automatic control of the result of solution of the simulation formula by means of the servo system is not more than 0.5%.

5. The error due to inequality of the heating temperature on the outer side faces of the plates is not more than 0.2–0.3%, since the heating of the two sides is equalized before the experiment.

6. The error due to inaccuracy of the simulation formula is not more than 0.5%.

Thus, the total error in the automatic determination of the temperature dependence of the thermal diffusivity by means of the electric computer is not more than 5–6%.

NOTATION

Here a denotes the thermal diffusivity; t_n is the temperature of heating of the outer side faces of specimens; Δt is the temperature drop on the specimen; l is the thickness of specimen; τ is the time; I is the output current of the converter.

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