DETERMINATION OF LOCAL HEAT-TRANSFER COEFFICIENT BY A DILATOMETRIC METHOD

V. S. Batalov

UDC 536.2.083

A dilatometric method of measuring the local heat-transfer coefficient and the experimental procedure involved are described; the theory of the method is given.

The previously noted [1] advantages of rapid, inertia-free dilatometry for measurement of the coefficient of heat transfer between the surface of cylindrical bodies and media apply primarily to the mean heat-transfer coefficients over the length (area) when the medium flows transversely over the surface. It is not difficult, however, to show that dilatometric methods still retain their advantages in the investigation of local heat-transfer coefficients.

We can use here the previous physical model, in which a transverse flow of medium over a cylindrical surface is investigated. It is not essential that the radius R is much less (two or three orders) than the cylinder length l, and the dilatometer does not measure the length, but the change in the diameter, of a standard specimen in time. The convenience of such an approach, in particular, is that we can always choose for the dilatometric measurements a portion of the cylinder on which there are no axial temperature gradients due to cooling resulting from convective heat transfer between the medium and the lateral surface (during the time required for the measurements, at any rate) and, thus, it is quite valid to assume that the axially symmetric temperature field on the selected region depends only on the time and the cylinder radius.

The relationships for calculation of the local heat-transfer coefficient are derived from the relationship known in the theory of thermoelasticity [2]

$$U_R = \frac{2}{R}\beta(1+\mu)\int_0^R T(r)\,r\,dr, \tag{1}$$

which gives the absolute thermal deformation of the radius U_R of a specimen with a thermal expansion coefficient β, within which there is an axially symmetric unidimensional temperature field $T(r)$, where μ is the Poisson ratio of the cylinder material.

The rate of change of the cylinder radius $W_R = dU_R/dt$ (in the case where the axis is fixed in space) can easily be obtained by differentiating Eq. (1) with respect to the time t:

$$W_R = \frac{2}{R}\beta(1+\mu)\int_0^R \frac{\partial T}{\partial t}\,r\,dr. \tag{2}$$

The value of $\partial T/\partial t$ in the cylinder is found from the heat conduction equation, which in cylindrical coordinates in the case of axial symmetry of the temperature field has the form [3]

$$\frac{\partial T}{\partial t} = \frac{\lambda}{c_p}\,\frac{1}{r}\,\frac{\partial}{\partial r}\left[r\frac{\partial T}{\partial r}\right), \tag{3}$$

where λ is the thermal conductivity of the specimen; c_p is the specific heat per unit volume.

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 18, No. 4, pp. 734-736, April, 1970. Original article submitted August 4, 1969.

Substituting the value of $\partial T/\partial t$ from Eq. (3) in formula (2) and integrating expression (2) we obtain

$$W_R = \frac{2}{c_p}\beta(1+\mu)\lambda\frac{\partial T}{\partial r}(R,\ t). \tag{4}$$

Since the heat transfer between the lateral surface and the medium conforms to the law

$$\lambda\frac{\partial T}{\partial r}(R,\ t) = \alpha(T(R,\ t) - T_1), \tag{5}$$

where α is the heat-transfer coefficient (local); $T(R, t)$ and T_1 are the surface temperature in the measured section and the temperature of the medium (which is assumed constant), we obtain

$$W_R = \frac{2\alpha}{c_p}(1+\mu)\beta(T(R,\ t) - T_1). \tag{6}$$

For further simplification of relationship (6) we use the fact that the product of the thermal expansion coefficient and the temperature drop between the surface and medium is the ultimate relative change of radius $\Delta R/R$, which occurs when the temperature of the measured section changes from $T(R, t)$ [in the case where the value of $T(R, t)$ is the same for all internal points of the section] to the temperature of the medium (after the change in dimensions is complete); hence,

$$\beta(T(R,\ t) - T_1) = \frac{\Delta R}{R}, \tag{7}$$

where ΔR is the absolute thermal change in the radius from the moment of measurement of the velocity W_R to the completion of thermal expansion.

Using Eq. (7) and relationship (6) we can put the formula for calculation of the local heat-transfer coefficient in the form

$$\alpha = \frac{W_R R c_p}{2\Delta R(1+\mu)}. \tag{8}$$

The local heat-transfer coefficient was measured with an optical interference dilatometer [4] in the Spectroscopy Laboratory of the Institute of Physics by sudden submersion of standard (copper) cylinders in a medium with constant temperature (water at freezing point, for instance). The initial temperature of the standard specimen was also constant (room temperature). The value of the measured local heat-transfer coefficient of the water in the case of natural convection was 590 $\mathrm{kcal/m^2 \cdot h \cdot deg}$.

In conclusion I consider it a pleasant duty to express my thanks to A. M. Leontovich and S. L. Mandel'shtam for help in the experiment and the opportunity given to me to carry out the necessary measurements in the Spectroscopy Laboratory of the Lebedev Physical Institute.

LITERATURE CITED

1. V. S. Batalov, Inzh.-Fiz. Zh., 17, No. 1 (1969).
2. A. D. Kovalenko, Introduction to Thermoelasticity [in Russian], Naukova Dumka, Kiev (1955).
3. P. J. Schneider, Conduction Heat Transfer, Addison–Wesley, Cambridge, Mass. (1955).
4. V. S. Batalov and V. É. Peletskii, Teplofiz. Vys. Temperatur, 6, No. 5 (1968).