LITERATURE CITED

1. V. G. Melamed, Heat and Mass Transfer in Rocks [in Russian], Moscow (1980).
2. S. E. Grechishchev, L. V. Chistotinov, and Yu. L. Shchur, Cryogenic Physicogeological Processes and Their Prediction [in Russian], Moscow (1980).
3. Yu. S. Danielyan, P. A. Yanitskii, V. G. Cheverev, and Yu. P. Lebedenko, Inzh. Geol., No. 5, 62-66 (1983).
4. I. I. Nesterov, Yu. S. Danielyan, P. A. Yanitskii, and V. I. Galieva, Dokl. Akad. Nauk SSSR, 277, No. 4, 928-932 (1983).
5. É. D. Ershov, Moisture Transport and Cryogenic Textures in Disperse Rocks [in Russian], Moscow (1979).
6. S. K. Godunov and V. S. Ryaben'kii, Difference Methods [in Russian], Moscow (1973).
7. P. J. Rouche, Computational Hydrodynamics [Russian translation], Moscow (1980).
8. V. E. Borozinets and G. M. Fel'dman, Probl. Kriolitologii, 9, 165-178 (1981).

CONVERSE THERMAL CONDUCTIVITY PROBLEMS AND CALORIMETRY OF TRANSPARENT BODIES

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UDC 536.6:535

The problem of measuring temperature of transparent bodies can be solved by use of transparent thin film resistance thermometers. Such sensors have been developed using tin and indium oxide. They are used to perform calorimetry of the properties of partially transparent bodies and laser radiation.

Colorimetry consists of methods for measuring the thermal effects accompanying physical, chemical, and biological processes. For the present we will understand this term to mean methods for determining the thermophysical properties of transparent bodies,* together with methods for determining energy characteristics of radiation.

The characteristics of laser radiation are most often determined by calorimeters with a load (calorimetric body) consisting of a more or less perfect ideal black body model [1]. In some cases it is desirable to use a completely or partially transparent colorimetric body, although problems then develop in measuring its temperature. If the temperature sensor has thermophysical and optical characteristics differing from those of the body whose temperature is to be measured, then the presence of other surrounding bodies with different temperatures, or the presence of radiation, either one cannot in principle measure the temperature of the given transparent body, or that measurement will require introduction of corrections which often are of significant complexity [2]. The difficulties in temperature measurement increase when the energy transport process is of a transient nature. In this case the corrections to the measurement may exceed the level of the temperature itself and change their algebraic sign in various stages of the process [3]. Thus, in recent years there has been a deliberate search for methods of measuring the temperature of transparent bodies. It is obvious that for this purpose one may use any phenomenon in which any optical or electrical characteristic of a substance changes with temperature [4-7].

One possibility for measuring temperature of transparent bodies reduces to creation and use of conductive thin-film coatings of a material transparent to the given kind of radiation, which are deposited on the surface of the body. Such thin conductive films can be used as

*The concept of a "transparent" body is an idealization. Herein by transparent we will understand bodies in which absorption of some portion of the passing radiation does occur.

Moscow Communications Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 56, No. 5, pp. 811-814, May, 1989. Original article submitted April 19, 1988.

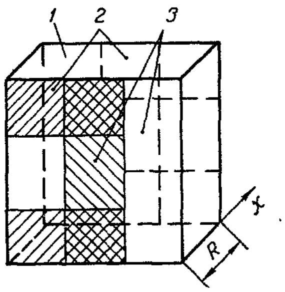

Fig. 1

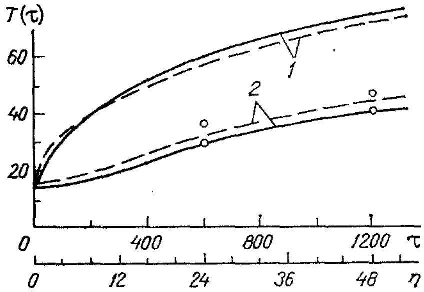

Fig. 2

Fig. 1. Calorimetric body model: 1) plate; 2) contacts; 3) FRT.

Fig. 2. Temperature field: solid curves, PK-1, experiment No. 3; dashes, PK-2, experiment No. 5; 1) T(0, τ), 2) T(R, τ); points, calculated values of T(R, τ). T, °C; τ, sec.

either resistance thermometers or thin-film thermocouples. Several problems of the theory of the transparent calorimeter were considered in [8], including specification of requirements for thin-film temperature sensors: low heat capacity as compared to the body whose surface temperature is being measured, sufficiently high thermal conductivity, thermometric parameters (resistance temperature coefficient or specific thermo-emf) which are constant over a certain temperature range and stable over time, and finally, transparency to the given type of radiation.

When these requirements are met, the temperature recorded by the sensor will obviously correspond quite closely to the body surface temperature. For simple bodies the temperature of internal points can be found analytically – from experimentally known surface temperature dependences. For complex methods numerical methods can be used.

Materials studied have shown that films of an In_2O_3–SnO_2 mixture have electrophysical and optical properties suitable for creation of film resistance thermometers (FRTs). Films with the required properties can be produced on glass substrates by reactive magnetron deposition of a target prepared from an alloy of In with Sn in an Ar + O_2 atmosphere with constant current and subsequent annealing [9, 10]. Depending on the deposition regime it is possible to obtain films of optical quality with surface resistances from tens of Ω/square to kΩ/square. The transparency range of such films extends from 0.4 to 1.2. Subsequent thermal processing permits increasing the transmission coefficient to 95% and stabilizing the resistance temperature coefficient.

The films thus produced were used for experimental testing of laser radiation flux density measurement and to determine thermophysical characteristics of partially transparent bodies.

One of the transparent calorimeter models (Fig. 1) consists of a plate of IKS-5 glass. Plate dimensions were 30 × 30 × 5 mm. Thin-film thermometers and electrical contact films were placed on its front and back surfaces. The plate was "irradiated" by the beam of an LG-106-M argon laser. The change in resistance of the FTR was recorded by an Shch-302 measurement complex. The FTR was calibrated before performing the measurements.

It was known from measurements performed by an IMO-2M calorimeter that the laser generated a continuously constant power level. Therefore in processing the experimental results, the solution of the thermal conductivity boundary problem describing the process of interaction of an incident constant density radiation flux with an infinite semitransparent plate in the absence of heat exchange at the boundaries (Eq. (2.55) of [8]) was used:

$$T(y,\,\omega)=\frac{R}{\lambda}\,E_0\left\{[1-\exp(-\varkappa R)]\,\omega\;+2\sum_{m=1}^{\infty}\frac{1+(-1)^{m+1}\exp(-\varkappa R)}{m^2\pi^2(1+m^2\pi^2/\varkappa^2R^2)}\times\cos(m\pi y)\,[1-\exp(-m^2\pi^2\omega)]\right\},\quad(1)$$

The problem was solved with a definite idealization of the process. Such assumptions as temperature dependence of the thermophysical properties and absorption coefficient were justified by the small change in temperature of the plate over the course of the experiment (Fig. 2). For the same reason neglect of energy redistribution due to intrinsic radiation and heat exchange on the surfaces is admissable. Scattering of the incident radiation was also neglected in solving the problem, which is obviously admissable if the distance at which scattering occurs is small in comparison to the other dimensions of the calorimetric body.

Equation (1) can be solved for the quantity E_0, and used as a solution of the converse problem for determination of the constant density incident radiation flux. For the case of variable power it is necessary to use other solutions of the converse problem; in particular, one can recommend the successive internal solution ([8], Eq. (2.59)).

To use Eq. (1) as a solution of the direct or converse problem it is necessary to know the values of the thermal conductivity and thermal diffusivity coefficients. No such data could be found in the literature for the glass used, so the authors were left with the task of determining values of the thermophysical characteristics. If the thermal flux density E_0 is known, the change in temperature of one surface can then be used to determine the value of the thermal conductivity coefficient. However another method was used in the present study. In the solution of Eq. (1) the time τ appears twice within the quantity $\omega = \mathrm{Fo} = a\tau/R^2$, as a cofactor in the first term and an exponent in the infinite series. Having chosen a time interval from the approximate estimate $\omega = 0.5$ (for which there is justification in [2]), we see that it is possible to neglect $\exp(-m^2\pi^2\omega)$. Further, since for IKS-5 glass $\kappa R \cong 10$, we may neglect the term $\exp(-\kappa R)$, calculate the sum of the infinite series for the coordinates $x_1 = 0$ and $x_2 = R$ and time $\tau \gtrsim 0.5R^2/a$ and write the solution of Eqs. (1) for the surfaces of the calorimetric body:

$$T(0,\ \tau) = \left(\frac{a}{R^2}\ \tau + 0{,}311\right) E_0\ \frac{R}{\lambda} \text{ and } T(R,\ \tau) = \left(\frac{a}{R^2}\ \tau - 0{,}164\right) E_0\ \frac{R}{\lambda}. \tag{2}$$

Solving these equations simultaneously, we obtain an expression for the thermal diffusivity coefficient

$$a = \frac{R^2}{\tau}\ \frac{0{,}311 T(R,\ \tau) + 0{,}164 T(0,\ \tau)}{T(0,\ \tau) - T(1,\ \tau)}. \tag{3}$$

Then, using the value of the volume heat capacity from [2, 11], we can calculate the value of the thermal conductivity coefficient $\lambda = ac\rho$ and use either of the expressions of Eq. (2) to determine the radiant flux density E_0.

Figure 2 shows the experimental and calculated data. The curves show surface temperatures at $x_1 = 0$ and $x_2 = R$, obtained in experiments with two calorimetric body models. The points are temperature calculations at $x_2 = R$ for temperature data at $x_1 = 0$ at two times corresponding to the values $\mathrm{Fo}_1 = 0.5$ and $\mathrm{Fo}_2 = 1.0$. With the first calorimeter model the flux density $E_0 = (8.6 \pm 0.2)\cdot 10^3$ while $E_0 = (5.5 \pm 0.5)\cdot 10^3$ W/m² for the experiment with the second model.

The good agreement between the radiant power density values calculated from data on the temperature of the frontal and rear surfaces of the calorimeter, together with the coincidence of the experimental and calculated values of rear surface temperature, with the calculation being performed for frontal surface temperature values indicates that the idealized pattern of the process for which the solution of Eq. (1) was obtained is close to a description of the real process.

In conclusion it must be noted that if the thermophysical characteristic values of the calorimetric body material are known, then the transparent calorimeter can serve as an absolute measurement device for the energy characteristics of the laser radiation.

NOTATION

T, temperature; E_0, radiant flux density on plate; $y = x/R$; R, plate thickness; κ, λ, a, absorption, thermal conductivity, thermal diffusivity.

LITERATURE CITED

1. R. A. Valitov and A. V. Kubarev (eds.), Measurement of Laser Characteristics [in Russian], Moscow (1969).
2. O. A. Sergeev and A. G. Shashkov, Thermophysics of Optical Media [in Russian], Minsk (1983).

3. V. N. Eliseev, V. I. Vorotnikov, V. A. Solov'ev, and V. A. Tovstonog, Isv. Vyssh. Uchebn. Zaved., Mashinostr., No. 1, 156-160 (1982).
4. A. P. Veduta and A. M. Leontovich, Zh. Tekh. Fiz., 37, No. 6, 942-946 (1967).
5. L. N. Kokhanenko and A. V. Antipov, Izv. Vyssh. Uchebn. Zaved., Fiz., No. 5, 33-36 (1969).
6. Device for Temperature Measurement, USSR Patent No. 821,957, G01 K 7/34.
7. E. Yoshinori and H. Toshija, Jpn. J. Appl. Phys., 18, No. 7, 1405-1406 (1979).
8. N. V. Shumakov, Successive Interval Method in Thermometry of Transient Processes [in Russian], Moscow (1979).
9. M. J. Ridje and R. P. Howson, Thin Solid Films, 96, No. 2, 121-127 (1962).
10. USA Patent I 4,400,254, 204-192, pub. Aug. 23, 1983.
11. I. K. Kikoin (ed.), Tables of Physical Quantities (Handbook) [in Russian], Moscow (1976).

APPLICATION OF A PRIORI INFORMATION TO ASSURE IDENTIFIABILITY OF A MATHEMATICAL MODEL

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UDC 536.241:517.914.4

The possibility of simultaneous determination of the heat elimination coefficient and the temperature of the environment as a function of two variables that are in the model in the same dimensionality as the desired quantities is studied.

To a significant extent the development of the theory of inverse problems broadens the data processing methodology. In particular, a study of questions of the identifiability of mathematical models displays the possibility of simultaneously finding a whole series of parameters of the object by observing its unique state function [1]. A computational-experimental determination of several unknown object characteristics at one time, including those that are difficult of access by direct measurements, permits realization of an interpretation of the results of a complex experiment in which the observations are performed by traditional control-measurement facilities. Consequently, it turns out to be possible to pose and solve a question on raising the informativity of observations with significant complication of the technical support of the experiment.

Planning and executing appropriate experiments should assure conservation of conditions to retain the mutually one-to-one correspondence between the desired quantities and the observable values of the object state. The method proposed in [2] can be utilized to investigate the mutually one-to-one correspondence between the coefficients of a mathematical model and its state that is considered given at each point of the domain of variation of the independent variables. The approach being developed permits answering a number of important practical questions on the identifiability of mathematical models by indicating in advance the class of ambiguity of the solution of the problem under consideration as well as obtaining simple criteria and conditions for conserving the mutually one-to-one correspondence needed for a preliminary estimation of the possibility of identifiability of the object under consideration.

By using this method, an analysis of heat-transfer processes was performed in [3], which answered the question of the possibility of simultaneous determination of both the heat elimination coefficient and the temperature of the environment by means of observation of the temperature field within the test object. One of the main results of this paper is the deduction that if finding the heat elimination coefficient and the temperature of the environment is not allowed under general assumptions about the properties of the desired quantities, then

Scientific-Production Combine "Kriogenmash," Balashikha. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 56, No. 5, pp. 814-819, May, 1989. Original article submitted April 19, 1988.

0022-0841/89/5605-0582$12.50