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A PROGRAMMABLE SUITE FOR IDENTIFYING THERMAL PARAMETERS IN ENGINEERING PROCESSES

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A system is described for identifying thermophysical characteristics and boundary conditions for heat transfer in pulsed processes.

Heat-treatment and strengthening techniques are often pulsed ones, with cycles lasting about 10^{-2}-10^{-4} sec, such as multipass grinding, laser hardening, and plasma treatment, or electrohydraulic pulse hardening. The same applies to rapid pulse methods of determining thermophysical characteristics.

Models may be written for such processes if they can be identified by solving interior and exterior inverse thermal-conduction problems. Short realization times impose special requirements on the identification system, which is a distinction from steady-state or slow nonstationary processes.

The coefficients in the conduction equation may be determined by an efficient pulse method involving laser heating [1], where a single experiment gives all the thermophysical characteristics: thermal diffusivity $a(T)$, specific heat $c(T)$, and thermal conductivity $\lambda(T)$, together with the latent heat of fusion, the emissivity, and the total emission. The method is a very convenient one and sometimes the only one for materials and composites such as powder steels, ceramics, evaporated thin films, multilayer systems, bimetals, molten metals, and heat-resistant protective coatings. The errors in determining $a(T)$, $c(T)$, and $\lambda(T)$ are [2] comparable with the errors in measuring the temperatures, while the method is readily automated.

One can determine the boundary conditions in heat transfer: heat flux densities $q(\tau)$, heat-transfer coefficients $\alpha(\tau)$, and the concentrations q_s and q_w of surface and bulk heat sources, by nonstationary methods with model systems and pilot plants.

This methodology in solving the interior and exterior boundary-value problems is based on nonlinear parametric optimization [3, 4]; one minimizes a functional

$$I = \int_0^{\tau} [T(r, \tau) - T_e(r, \tau)]^2 d\tau \Rightarrow \min$$

and uses a combination of iterative gradient and search optimization methods.

This suite for identifying thermal parameters includes the following:

1) a GOR-100M laser with nominal output up to 90 J, pulse length 1 msec, wavelength 0.6940 μm, and spot diameter 0.1 mm, together with fast temperature sensors, an S13-1 stor-

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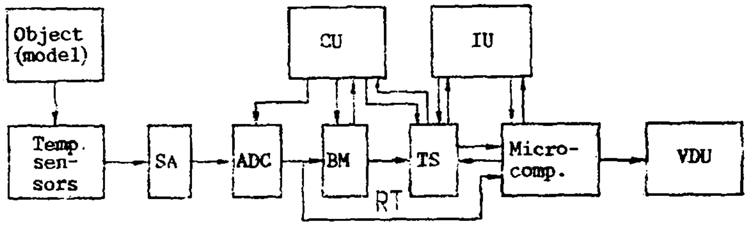

Fig. 1

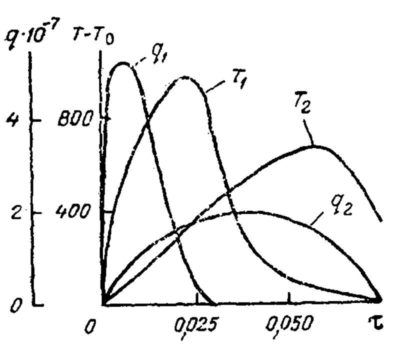

Fig. 2

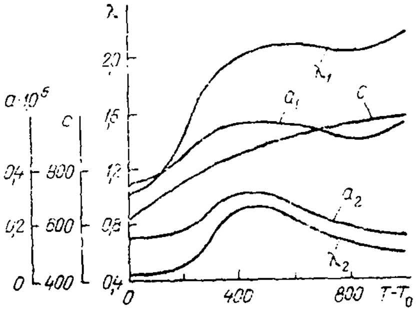

Fig. 3

Fig. 1. Suite block diagram: SA) scaling amplifier, ADC) analog-digital converter, BM) buffer memory, TS) tape store, CU) control unit, IU) input unit, RT) real-time operation.

Fig. 2. Heat flux density q and surface temperature T on ceramic grinding: 1) longitudinal feed S = 0.33 m/sec; 2) S = 0.1 m/sec; q in W/m^2, $T - T_0$ in K, and τ in sec.

Fig. 3. Thermophysical characteristics for powder steel (50% Al_2O_3 + 50% Cr): 1) sintered; 2) freely poured; a in m^2/sec, c in J/kg·K, and λ in W/m·K.

age oscilloscope, and a DVK microcomputer for determining the thermophysical characteristics; and

2) fast temperature sensors, recording system consisting of two independent subsystems for recording and inputting the data to a computer, together with a DVK microcomputer with graphics VDU for outputting the data and the final parameters (for determining boundary conditions).

Figure 1 shows the block diagram. The suite records the parameters in pulsed processes on magnetic tape in digital form, which can then be processed by microcomputer to identify the thermal parameters. The suite has been described in [5].

The software provides two modes of operation: with storage and with control in real time. In the first, the input data are preprocessed and written to tape for subsequent processing by microcomputer to identify the parameters. In the second, the parameters are calculated from the incoming data and a comparison is made with the optimal states on the basis of an optimal-control program, from which an error signal is generated for transmission via the digital-analog converter to the control system. The two modes of operation mean that the suite can be used not only to identify parameters but also to monitor and control the process [5].

The suite has been tested on prototype plant used in multipass diamond grinding with preliminary plasma heating applied to materials difficult to work, as well as in determining thermophysical characteristics for powder steels. Figure 2 shows surface temperature T measurements in grinding a ceramic with a special diamond wheel and calculations on the heat flux density q from the wheel on the basis of the [6] solution to the inverse thermal-conduction problem [3, 4].

Figure 3 gives the thermophysical characteristics for powder steel.

NOTATION

a, thermal diffusivity; c, specific heat; λ, thermal conductivity; T, temperature; τ, time; q, heat flux density; α, heat-transfer coefficient; r, spatial coordinate. Subscripts: s, surface; w, volume.

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HIERARCHIC THERMAL-PROCESS IDENTIFICATION IN DEVISING TECHNICAL SCHEMES

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Hierarchic-identification principles and a block diagram are given for developing heat-engineering techniques.

A systems approach is required at all levels in the hierarchy in devising new heat-engineering systems and technologies [1]; as regards heat-process simulation, this involves the following stages: design, which involves structural and parameterric optimization; multifunctional adjustment to the optimum mode of operation (debugging the system or process to provide efficient and reliable operation under various conditions); and optimum control in real time.

A given process can be represented by a set of models, which differ in the number of factors, the completeness, the description accuracy, and the complexity [2]. The target in each stage $\Phi^{(k)}$ correspondingly has models $M^{(k)}$ consisting of differing sets of parameters $P_i^{(k)}$ and control inputs or optimization parameters $U_i^{(k)}$, while including various constraints and assumptions $G_i^{(k)}$. Consequently, thermal processes must be identified in implementing new methods of managing component and technological-scheme design [3] at several levels appropriate to the stages of development, i.e., one has a hierarchic system.

A method has been described [4] for analyzing the thermal conditions in a complicated object, which involves applying a series of models differing in detail in the temperature-pattern description.

Figure 1 shows a hierarchic-identification diagram applicable to heat-engineering development. The hierarchic system includes:

1. A set of models describing the thermal processes and the operation of the heat system or technology. The models in the form of boundary-value treatments contain information on the process physics, while regression-type models describe the structure and the relations between the factors [5].

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