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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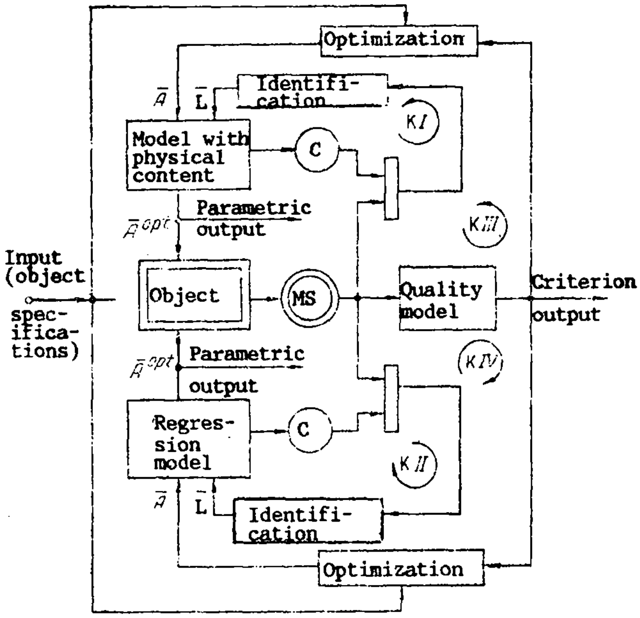

Fig. 1. Structural diagram for hierarchic model identification in combined analytic and experimental optimization: $\bar{A}$ vector for the design and adjustment parameters, $\bar{L}$ identifier vector, MS measurement system, KI and KII identification loops, and KIII and KIV optimization loops. C is computer.

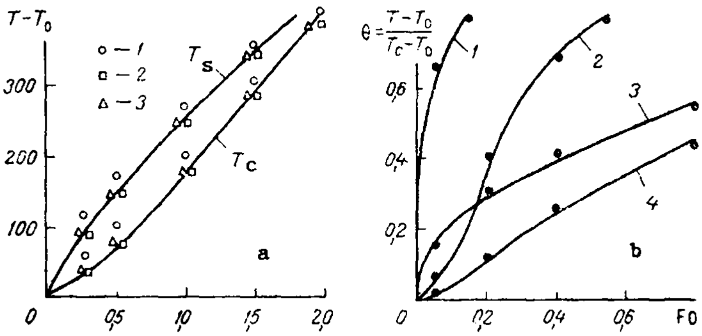

Fig. 2. Comparison of spline approximation for temperatures (a) and functional working models (b) with an analytic method (curves) and a finite-difference method (1): a: 2) r spline; 3) τ spline; T_s and T_c tempertures at the surface and center of a solid cylinder; b) points for functional working model $\theta = \varphi(Bi, \eta, Fo)$, $Bi = \alpha R/\lambda$, $\eta = R_0/R$, $Fo = a\tau/R^2$, $\eta = 0.4$; 1, 3) Bi = 10.0; 2, 4) Bi = 1.0; 1, 2) $r = R_0$; 3, 4) $r = R$.

2. A set of qualitative models that define the optimality in the complexity and detailing in the individual development stages on set criteria.

3. Closed loops providing structural and parametric identification and thus optimality in the model on set criteria such as [6].

4. Conditions for combinations of full-scale experiments on model equipments or pilot plant, together with computer experiments. A distinctive feature is that the method combines plant experiments with computational ones in a single iterative parametric synthesis. In developing advanced technologies such as depositing thin films, heating and pressing powders, strengthening materials, etc., computer experiments represent an effective means

on the one hand of reducing the development time considerably and on the other of ensuring optimum equipment parameters and characteristics [3].

In multicriterion optimization for heat equipment parameters and thermal conditions as in

$$\min F(\bar{P},\ \bar{\alpha} = \{N[T(\bar{r},\ \tau),\ \tau],\ M[T(\bar{r},\ \tau)]\},\ G(\bar{P},\ \bar{\alpha}) \geqslant 0,$$

one needs multiple calculations on the basis of optimum computer-experiment planning [7], which may be implemented by spline approximation for the temperatures at the nodes in a net:

$$T^{i,k}(r) = \sum_{\alpha=0}^{2} C_{\alpha}^{i,k}(r - r_{i-1})^{\alpha},\ r_{i-1} \leqslant r \leqslant r_i,$$

or

$$T^{i,k}(\tau) = \sum_{\alpha=0}^{2} C_{\alpha}^{i,k}(\tau - \tau_{k-1})^{\alpha},\ \tau_{k-1} \leqslant \tau \leqslant \tau_k,$$

in accordance with the class of job and the conditions for simulating the initial differential equation to the best effect in a certain sense.

Optimal process control requiring real-time calculations imposes stringent constraints on the model complexity and completeness. Here one uses working models derived by simulating the relationship between the control U and the process parameters P in the functional region Φ subject to given constraints on the control G and the phase variables H in the form $U \in G: \{P \in \Phi \wedge X \in H\}$, where region H is split up and spline descriptions are used for the functional relationships in each subregion.

Figure 2 compares spline approximation and working models with the analytic and finite-difference methods.

This system gives a model adequately describing the process and meeting the functional requirements as defined by the customer while at the same time providing computational simplicity and testable accuracy. The structure and the closed-loop hierarchic identification not only ensure that the working models fit the plant tests and provide optimality but also enable one to evaluate the soundness of the physical hypotheses used in the models. This is done by combining two lines of identification: hierarchic model transformation to give working models and check parameter evaluation from those models via the plant experiments. The identification is realized by means of Bayes estimators in combination with efficient nonlinear parametric-optimization algorithms [7], which substantially improves the development performance and reduces the time needed to set up and commission complex systems.

The performance in this approach has been demonstrated in parametric synthesis for heat-engineering systems and production technologies [3].

NOTATION

T, temperature; τ, time; r, spatial coordinate; C, spline coefficients; Φ, functional domain; P, process parameters; U, control parameters; G, control restrictions; H, phase-variable restrictions; Bi, Biot number; Fo, Fourier number. Subscripts and superscripts: i, k, coordinate and time net points.

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