The previous All-Union seminar demonstrated the rising level of development in inverse-treatment methods. There have also been new developments in inverse-treatment theory, which are related to current industrial requirements. One needs a strict mathematical basis for all these methods, particularly in order to analyze the correctness. We consider that applied methods need further development, particularly in planning experiments involving several monitored variables, nonlinearities in models, and when the conditions vary over time.

Experience in solving inverse problems accumulated in recent years enables one to set up problem-oriented software to extend the use of these methods.

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NONSTATIONARY HEATING MODELS IN THE THERMAL DESIGN OF HEAT-SHIELD SYSTEMS FOR RECOVERY VEHICLES: INVERSE THERMAL-CONDUCTION PROBLEMS

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Applications of inverse-treatment methods are examined in the development of heat-shield systems.

In the design of vehicles intended to take equipment and teams to planets, an important part is played by the heat-shield system, which protects the instruments and team from the high thermal loads occurring. Designing these systems involves solving some complicated problems, one of which is the interaction of hot gas with the shield material, in order to choose the most effective materials [1].

In general, this involves solving differential equations for nonstationary heat and mass transfer in a gas–solid system. Experiment plays a considerable part in research on such phenomena, and improvements in performance here are undoubtedly dependent on the use of the latest mathematical methods at all stages in the preparation, execution, and data processing, which also require the general use of the latest engineering facilities.

Computerized data-acquisition systems are widely used, in which the software provides methods of solving inverse heat-transfer problems IHP in various ways: determining limiting heat-transfer conditions, identifying heat and mass transfer processes, recovering temperature patterns, etc. It is particularly important to recover thermal boundary conditions and temperature patterns in materials from temperature measurements within specimens of composite heat shields stressed by intense heating.

An extremely promising approach to IHP is based on iterative methods [2]. The inverse problem is then formulated as a problem in optimal control, in which the unknown functions or parameters (controls) are selected to minimize the mean-square discrepancy. IHP are solved iteratively by gradient minimization methods in combination with halting the search on a discrepancy principle, i.e., on matching the minimized functional up to the integral error in the experimental data. The gradient can be calculated by numerical differentiation and by solving the problem for the conjugate variable. The available data confirm high performance for numerical algorithms based on this approach in boundary-value and coefficient-type inverse problems.

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The applications of iterative methods are constantly extending. In particular, an algorithm has been proposed for the parametric identification of models describing nonstationary heat transfer in the ablation of heat-shield materials interacting with gases. The unknown characteristics are then the functional parameters in the heat-balance equation for the ablating surface, for example, the integral degree of blackness as a function of surface temperature together with the heats of the physicochemical transformations in relation to the ablation rate. In general, the problem does not have a unique solution. Consequently, one processes the data from several experiments at different thermal loads together.

Identification for model characteristics is important not only for passive heat shields but also for active ones, for example, porous shielding with gas cooling. The performance of such a system is determined not only by the extent to which the heat transfer at the outer surface is altered on injecting the coolant into the boundary layer but also by the internal heat transfer, where the coolant passing toward the outer surface takes up heat from the porous framework. Experiment at present gives the most reliable information on local heat-transfer coefficients and internal heat transfer in porous bodies.

As heat and mass transfer are very rapid in boundary layers, particular importance attaches to algorithms for recovering thermal boundary conditions at the outer surfaces of porous bodies from temperature measurements in the porous framework, i.e., from solving inverse problems. In that case, the boundary IHP is formulated for an equation system describing nonstationary heat transfer in a porous body with forced gaseous coolant flow.

Another important application of inverse-treatment techniques is the joint determination of internal heat-transfer coefficient and effective thermal conductivity for a porous framework. However, in that case there are fairly strict limitations on the existence and uniqueness of the solution to the corresponding inverse problem.

Practical use of iterative algorithms in IHP has shown that the performance, accuracy, and reliability are largely dependent on the conditions in the experiments and the temperature-measurement systems: the number and location of the temperature sensors.

In many thermophysical researches, one knows in advance the experimental conditions, the thermophysical properties of the materials, and the geometrical dimensions of the specimens. Therefore, the unique effect on the IHP accuracy derives from the choice of the number and locations of the temperature sensors. The minimum number of measurements, and sometimes the disposition of them relative to the heated surface, are also determined by the conditions for the existence and uniqueness of a solution. On the other hand, using additional sensors improves the reliability.

In this connection, we can consider measurement planning, which involves choosing a measurement plan (vector for the coordinates of the measurement points) in order to provide the maximum accuracy in determining the unknown characteristics and the best performance (convergence, stability, etc.) in the IHP algorithms.

The plan-selection criterion can be based on various functionals of the normalized information matrix [3], which reflects the sensitivity of the thermal system at the points of measurement to small changes in the unknown quantities. As the elements of that matrix are dependent on the true values of the quantities, one can speak only of constructing locally optimal plans by the use of *a priori* information on the vector for them.

This optimal planning problem can also be reduced to the solution of a corresponding peak-holding one.

The optimum plan choice should be supplemented with analyzing the sensitivity of the planning criterion to possible variations in the coordinate vector in order to identify the region of possible sensor locations as well as to estimate the possible accuracy loss due to uncertainties in the sensor coordinates.

Therefore, there is scope for further improvement in experimental performance from developing inverse-treatment techniques for identifying model characteristics for heat and mass transfer in heat-shield systems, which may be combined with measurement-planning methods.

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IDENTIFICATION OF PHYSICAL PROCESSES AND INVERSE PROBLEMS

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General procedures of parametric and structural identification are considered as are inverse problems as their methodological basis.

The progress of physical processes in different media (gases, liquids, solids) can be assessed according to some external phenomena that are recorded by special devices. Relying on the results of observations (measurements) as well as on general physical laws and regularities, the process being studied can be compared to some mathematical model. The development and founding of the mathematical models are often called identification.

A mathematical model (MM) as an abstract means of the approximate representation (mapping) of a real process in order to investigate it is the mathematical description of substantial factors of the process and its interconnections. A certain set of models, distinguished particularly by the number of factors being taken into account and by the completeness and accuracy of description of the process, respectively, on the one hand and by the complexity of the model on the other, can ordinarily be compared to the identical process. One of the main requirements on a MM is the need to take account of all fundamental factors and interconnections of the process under consideration and the elimination of the secondaries. The selection of a model is dictated primarily by the purpose of the investigation being performed, here the tendency is always ultimately to simplify the model so as to make its practical application possible and convenient.

Therefore, the first step in the mathematical formulation of a problem in the general case is reasonable construction of the model structure, i.e., a qualitative description of the process under investigation by using some operators. This procedure is called structural identification.

Differential operators most often comprise the basis of mathematical models of physical processes. Models with lumped parameters described by ordinary differential equations and models with distributed parameters described by partial differential equation are differentiated.

The second step in the mathematical formulation of a problem is the "allotment" of the model of quantitative information, i.e., the determination (estimation) of the unknown characteristics (model parameters) in the structural MM. This stage is called parametric identification.

Structure and parametric identification of physical processes are closely related to the solution of inverse problems for differential equations. The formulations of direct problems, each of which can be compared with a certain set of inverse problems within the framework of the model being identified are assumed known in the formalization of the general formulations and extractions of the fundamental classes of inverse problems. Characteristic examples of inverse problems are presented below.

SYSTEMS WITH LUMPED PARAMETERS

Let the process being investigated be characterized by n dependences of the scalar argument t (variables of coordinates of the process): $y(t) = [y_1(t), \ldots, y_n(t)]^T$, and in conformity with a certain mathematical model this vector will satisfy a system of ordinary differential equations of the form

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