INVERSE PROBLEMS AND THE DESIGN OF COMPLEX ENGINEERING SYSTEMS*

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A study is made of the use of inverse heat- and mass-transfer treatments during thermal design and in research on high-temperature loading in engineering systems.

Considerable thermal loads are usually involved [1] in modern engineering systems such as aircraft, engines, and power plants. Therefore, aspects of the thermal design of these now have very great importance [2]. For example, high-speed aircraft require research on thermal protection systems, which usually must be based on discussing the heat and mass transfer in a gas—solid system, i.e., involves a thermal design problem [3]. Various experimental methods of researching heat and mass transfer are also important in thermal design.

Here we would emphasize that science and industry in this country have to make considerable efforts to accelerate scientific and technical progress, in accordance with the directives of the April 1985 meeting of the Central Committee of the CPSU. Rapid industrial developments involve accelerating scientific research and the rapid implementation of the results in production. These tasks require the latest research methods for physical processes, including heat-transfer ones. Methods based on inverse treatments in heat and mass transfer improve performance in thermal design and facilitate the proper study of the physical characteristics of materials. These methods have acquired an important place in experimental researches and have become a reasonably universal means of obtaining reliable information on the states of physical objects [4].

Inverse treatments involve finding the causes from known effects. They can therefore be used in determining design characteristics on the basis of possible thermal effects. For example, estimates of external thermal loads can be used with existing models for the interaction of an aircraft with its environment to choose materials for thermal shields. Design consists of determining the general appearance of the aircraft and may amount to constructing a model in the form of algorithms giving the characteristics. To formulate a model with allowance for the heat loads, it is necessary to have not only a set of thermal-design equations but also a link to simulation treatments for thermal conditions.

Increasing use is being made of methods providing optimum organization (planning) in data processing. Much attention is being given to the theory of experiment planning and general solution methods. However, as yet, applied planning methods are inadequately developed, particularly for thermal experiments.

In thermal design, one frequently has to consider topics requiring a knowledge of detailed physical processes accompanying heating, erosion, and heat transfer in complex systems and so on. Therefore, it is not accidental that there is increasing interest in research methods based on solving inverse problems. The Fifth All-Union Seminar on Inverse Problems was held in Ufa in September 1984, and this showed that these methods are being used to advantage in various areas in this country. Scientific centers are developing the theory and setting up new methods of researching heat-transfer processes on the basis of inverse treatments. These methods are now used in many branches of industry: power engineering, general engineering, instrument design, metallurgy, etc. The methods are used to optimize temperature measurements and to examine atomic recombination at surfaces. In metallurgy, inverse-treatment methods make it possible to determine heat-transfer parameters in casting. Inverse treatments in metal rolling and in the production of fiber optics are also widely used, as also in the diagnosis of high-temperature processes and in determining the thermophysical characteristics of constructional materials.

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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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