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HIGH TEMPERATURES MEASUREMENT AND RECONSTRUCTION IN HIGH-SPEED FLOW

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Temperature measurement is important and consequently the well enough investigated direction in the metrology. Application of the traditional contact methods (thermocouples, resistance thermometers) and the optical technique (pyrometers, Rayleigh's scattering, the laser-induced fluorescence) allow to receive comprehensible accuracy of measurements. These methods have the advantages, lacks and restrictions, and consequently they are suitable selectively in various conditions. Application of the contact methods for measurement of high temperature (more 2000K) is limited in view of temperatures of melting and the high time lag of sensitive elements. Therefore, the thermojunction condition can be too far from a stationary state. Optical methods, which allow to measure high temperatures, are limited since it is necessary to guarantee of an optical way. Realization of optical measurements of temperature in the channel becomes frequently impossible just for this reason. At researches in high-speed wind tunnels with a short operating time from 5 to 100ms, this problem of measuring system can be unsolvable. The problem becomes especially topical at definition of temperature fields if it is necessary to measure the temperatures in the channel.

In present work, results of the analysis of gas temperature measurement in the channel are presented at change of the temperature from 1500K to 3000K in a hot-shot wind tunnel at the Mach numbers of 5 - 8, and total pressure up to 2MPa. The total temperature at the channel exit was measured by means of the rake consisting of 5 gas-flow hromel-alumel thermocouples with the sizes of measuring junction of 0.05, 0.1 and 0.2mm. The minimum sizes of thermojunction are chosen for decrease of the response time at measurement under the conditions of short-time operation of wind tunnel. The rake construction is manufactured so that identical dynamic and thermal conditions were provided before the entrance in the each thermocouple channel.

Two approaches were used to reconstruct real temperature values and inertial characteristics of the measurement apparatus. Method of two thermocouples is based on usage of the positions of temperature maximum depending on time. Deconvolution method uses the solution of convolution integral equation [1]. Such methods employ a heat transfer differential equation of the ideal thermal detector [2]. Thermocouples calibration was done by measurements of temperature steps. Measurements, as a temperature step, are necessary for this purpose. Such step has been obtained on the basis of calibrating measurements.

For processing of the obtained experimental data and to implement reconstruction of real temperature under indications of two thermocouples have been used two different approaches. The first signal processing is based on use of indications of two thermocouples with diameters 0.1mm and 0.2mm, and the data on change of Reynolds number during an operating mode of a impulse wind tunnel. The results obtained have shown (Fig. 1) that the developed technique of the signal reconstruction allows with sufficient accuracy to define total temperature in wind tunnel at short-time action. Results of reconstruction of total temperature by means of this technique are presented in Fig. 1 (red line). They have confirmed possibility of determination of maximal temperature and applicability of such approach for a wide class of the tasks.

Second temperature reconstruction method was based on deconvolution of integral equation. Kernel of this equation was restored by differentiation of the thermocouple experimental output response to the temperature step input signal. Curves of ThCoup0.1mm and 2 of ThCoup 0.2mm in Fig.2 correspond to temperature measurements by two thin thermocouples with diameters 0.1 and 0.2 mm, and curves of 3, 4 (Reconstr 0.1 and 0.2mm) are result of solution (deconvolution) of integral equation for curves 1 and 2. Before deconvolution experimental signal was smoothed by splines. Convolution kernels were chosen as decreasing exponents with a single unknown parameter, namely, half-width. During deconvolution the regularization procedure in the Fourier domain was used. Half-width parameter searching was done by minimization of residual norm, and resulted in the next values: the first half-width is approximately 20 ms and the second is 40 ms.

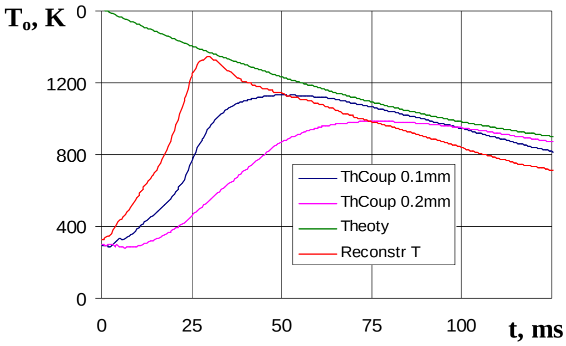

Fig. 1. Total temperature reconstruction result: method of two thermocouples.

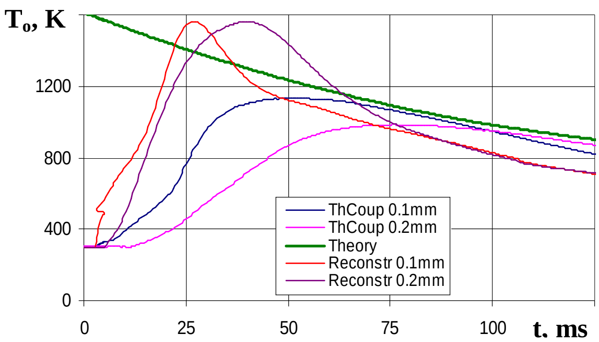

Fig. 2. Total temperature reconstruction result: deconvolution approach.

One can see that the results, obtained by developed techniques of the signal reconstruction, well enough conform to each other. The estimation of an error of total temperature definition by means of the offered approaches has demonstrated that the temperature can be reconstructed with accuracy not worse than 8%.

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