IDENTIFICATION OF THE TEMPERATURE AND EMISSIVITY FROM THERMAL RADIATION SPECTRUM OF HEATED BODIES

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Let $I_0(M, \boldsymbol{s}_M, \lambda_i, T_{br}(\lambda_i))$ be a spectral intensity of an emitting opaque heated body at points M in directions $\boldsymbol{s}_M$. The intensity is supposed to be recorded directly by a pyrometer at known wavelengths $\lambda_i, i = 1,\ldots,m$, or to be found from measured brightness temperature $T_{br}(\lambda_i)$. The intensity and the emissivity $\varepsilon(M, \boldsymbol{s}_M, \lambda_i, T_M)$ are related in the form

$$\varepsilon(M, \boldsymbol{s}_M, \lambda_i, T_M) I_0(\lambda_i, T_M) = I_0(M, \boldsymbol{s}_M, \lambda_i, T_{br}(\lambda_i)), \quad (1)$$

where $I_0(\lambda_i, T_M)$ is represented by the Planck formula. Assuming the values $\varepsilon(M, \boldsymbol{s}_M, \lambda_i, T_M)$ of emissivity and the temperature T_M to be unknown we can consider the relation (1) as the system of m equations with $m+1$ unknowns.

The similar approach is valid for a system of reradiative isothermal opaque surfaces. Suppose that the spectral intensity $I_{ef}(M, \boldsymbol{s}_M, \lambda_i)$ of effective radiation at points M in directions $\boldsymbol{s}_M$ is recorded in this system. If we wish to find the temperature T_M along with unknown values $\varepsilon_{ef}(M, \boldsymbol{s}_M, \lambda_i)$ of the effective emissivity, we obtain the equations

$$\varepsilon_{ef}(M, \boldsymbol{s}_M, \lambda_i) I_0(\lambda_i, T_M) = I_{ef}(M, \boldsymbol{s}_M, \lambda_i), \quad i = 1,\ldots,m. \quad (2)$$

It is well known that the equations (1), (2) have ambiguous solutions. So, we have to use additional assumptions to find both the temperature and the emissivity from (1) (or from (2)). For example, we can postulate that the function ε (or ε_{ef}) is independent on λ ('grey' thermal radiation), or depends on λ linearly, or is represented by a polynomial of n-th order, or has more complicated form. The unknown coefficients of these postulated functions should to be identified.

We propose a new numerical algorithm for the identification of temperatures and emissivities from (1) or from (2). The input data for the algorithm is a registered spectral distribution of thermal radiation intensity, while the output values are the calculated estimate for the temperature and the 'best' parametric formula for the emissivity chosen from a database of such formulas. The algorithm is based on regularized sequential optimization procedures[1] with specially calculated initial guesses for the temperature and the emissivity as a function of the wavelength. Each step of the algorithm refines the temperature and/or the formula for the emissivity going to more complex dependence (generally, nonlinear with respect to the wavelength and/or parameters). The algorithm was examined for the 'quasi-real' data generated with the help of experimental normal emissivities for tungsten, tantalum, molybdenum, niobium and liquid zirconium as well as for an isothermal tungsten cavity. In doing so, we used the well-known experimental emissivities and known corresponding temperatures to calculate the values I_0 from (1) (or I_{ef} from (2)). Then we perturbed these values by model random errors with levels near to the experimental ones and used such input

data in the algorithm. The trials demonstrated the numerical stability of the algorithm with respect to disturbances of the data.

The next table illustrates the results of our numerical experiments. Here T_0 is given true temperature and T_{calc} is calculated one. The values $\Delta T = |T_{calc} - T_0|$ and $\Delta T/T_0$ describe correspondingly the absolute and relative errors of the found temperature. The levels of random perturbations for the data are characterized by relative mean square errors δ_{ex}. The value δ_{ε} represents the relative mean square error of calculated emissivity, while δ_{appr} is the relative residual of the equation (1) (or (2)) for the found temperature and emissivity. The references show the origin of the experimental emissivities.

Table. Calculation results.

№	Substance, spectral range (μ m), true temperature	Number of algorithm step	T_{calc}, K	ΔT K	$\Delta T / T_0$	δ_{appr}	δ_{ε}	δ_{ex}
1	Tungsten [2]	1	1976	24	0.012	0.0077	0.1430	
	$\lambda \in [0.55, 0.9]$	2	1996.6	3.4	0.002	0.0037	0.0187	0.0005
	T_0=2000 K	3	1997.1	2.9	0.001	0.0000	0.0162	
2	Tantalum [2]	1	1996	4	0.002	0.0639	0.0579	
	$\lambda \in [0.4, 1.2]$	2	1996	4	0.002	0.0027	0.0260	0.0005
	T_0=2000 K	3	1996	4	0.002	0.0000	0.0258	
3	Molybdenum [3]	1	1996	4.1	0.002	0.5015	6.5078	
	$\lambda \in [0.4, 2.4]$	2	1996	4	0.002	0.0113	0.0241	0.0005
	T_0=2000 K	3	1996	4	0.002	0.0000	0.0215	
4	Niobium [4]	1	2001	1	0.0005	0.6308	1.4580	
	$\lambda \in [0.68, 5.01]$	2	2001	1	0.0005	0.0049	0.0061	0.035
	T_0=2000 K	non						
5	Zirconium (liquid) [5]	1	2296	39.1	0.017	0.1527	0.1868	
	$\lambda \in [0.38, 0.93]$	2	2343	7.7	0.003	0.0253	0.0391	0.05
	T_0=2335 K	3	2339	4.5	0.0019	0.0000	0.0205	
6	Cavity [6,7]	1	2078	77.6	0.039	0.0306	0.3224	
	$\lambda \in [0.55, 0.9]$	2	1999	1.3	0.001	0.0002	0.0070	0.0005
	T_0=2000 K	non						

Quasi-real data of $\varepsilon_{ef}(\lambda_i)$ correspond to radiation of a model of cylindrical cavity of infinite length with slit at $\omega = 5^0$, the tracking surface element being located against the slit [6]. The cavity has the temperature $T = 2000\,K$, is manufactured of tungsten, emissivity data are taken from [7].

The analysis of our numerical trials leads to the following conclusions.

1. The presented algorithm provides in practice a reasonable accuracy for the identification of temperatures and emissivities.

2. The a priori information on the optical properties of the surface material (as a function of wavelength and temperature) is of principal significance for the identification. In general, it is necessary to perform a mathematical modeling to substantiate the parametric form of the emissivities to be found.
3. In searching the best parametric emissivities, we observed a sharp growth of the error δ_ε with increase of the number of unknown parameters. So, it is reasonable to 'truncate' the number of parameters depending on the error levels of experimental data in order to obtain the reliable results.
4. The database of the parametric models for ε or ε_{ef} incorporated in the algorithm can be easy changed or extended depending on the material of the emitting body and/or its surface properties.

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