Journal of Quantitative Spectroscopy & Radiative Transfer 101 (2006) 73–86

Journal of Quantitative Spectroscopy & Radiative Transfer

www.elsevier.com/locate/jqsrt

Inverse estimation of temperature dependent emissivity of solid metals

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Received 5 January 2005; accepted 16 November 2005

Abstract

An algorithm in the form of inverse problem to estimate the surface emissivity versus temperature of solids of variable thermal properties separated by a non-participating medium is proposed. The estimations are reproduced by the connection of variable slope stretches (piece-wise function) with no information of the temperature dependence of the emissivity. The input data (measurements) come from the solution of the direct problem by adding a random error to the temperature field. Both the direct and inverse problem are numerically solved by means of the network simulation method. The influence of different parameters in the estimation is studied and the resulting estimations are compared with exact solutions in order to verify the effectiveness of the proposed method.

Keywords: Total emissivity; Inverse problem; Function estimation; Network simulation

1. Introduction

Thermal radiation occurs in many industrial applications such as heating, cooling and drying, as well as in the energy conversion processes that involve fossil fuel combustion and solar radiation [1]. It also occurs in advanced technologies, for example during rapid solidification by means of thermal sprays and in radiators of drop liquid for airships [2–4]. A knowledge of the temperature dependence of the surface emissivity, which controls the radiative problem, is fundamental for determining the thermal balance of these processes.

Surface emissivity strongly depends on the nature of the surface (composition, roughness, etc.), on the surface temperature, and on other factors [5] which, in turn, can be influenced by the method of fabrication, thermal cycling, and chemical reaction with the environment. What is clear is that total emissivity depends mainly on temperature, which may be significant. The experimental methods [5,6] used to determine this property are very complicated and require many measurements if the temperature range is large. However,

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0022-4073/$ - see front matter
doi:10.1016/j.jqsrt.2005.11.005

Nomenclature

C	heat capacity ($\mathrm{kJ\,m^{-3}\,K^{-1}}$)
C	capacitor and capacitance (F)
E	voltage-control voltage-source
e	average relative error in Eq. (15)
F	functional defined in Eq. (13)
G	voltage-control current-source
h	weak heat transfer coefficient ($\mathrm{W\,m^{-2}\,K^{-1}}$)
J	electric current variable (A)
j	heat flux rate ($\mathrm{W\,m^{-2}}$)
k	thermal conductivity ($\mathrm{W\,m^{-1}\,K^{-1}}$)
K	initial slope increment of the stretch
L	thickness of the slab
n	integer number
N	number of volume elements
$r_{z,f}$	number of terms within the functional for each sensor and each stretch
P	total number of temperature sensors
R	resistor, Ω
t	time, s
T	temperature (K)
V	voltage (V)
x	spatial co-ordinate
Z	number of stretches of the piece-wise function in the IHCP
ΔC	deviation of the capacity heat in relation to the mean value
Δx	thickness of the control volume
ΔT_{a}	temperature interval of the stretches associated to the functional
Δt	interval of time between measurements
Greek symbols	
β	integer number, $1<\beta<n$, in Eq. (6)
δ	convergence criteria
ε	total emissivity
λ	reduction factor for the slope
μ	normal random error
θ	measurements error in percentage
σ	standard deviation of the measurements
σ_b	Stefan–Boltzmann constant, $5.67\times10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$
ω	random number variable
Subscript	
av	mean value
con	convection
end	value of temperature of the last stretch
est	estimate value
ex	exact value
f	particular location at the slab
i	associated to the volume element i, $1\leqslant i\leqslant N$; also the centre of the volume element
$i\pm\Delta$	right and left ends of the volume element
ini	relative to the first stretch
inv	refers to the solution of the inverse problem
j	1, 2, …, p
m	measurements