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Infrared Temperature Measurement System applied to the Measurement of Thermal Diffusivity

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Abstract

The Laser Flash measurements for thermophysical properties determination is based on measurements of dynamics temperature transients. The dynamic effects or thermal inertia of commercial temperature measurement systems are representative and could not be ignored due to the fast dynamics of the measured thermal transients. This paper presents a mathematical modeling developed for the infrared temperature measurement system of an experimental system for thermal diffusivity measurements based on the Laser Flash Method. This reduced price and suitable developed system is based on commercial Dewar infrared detectors, collimation lens and a mathematical model developed on LabVIEW framework. As result, the electric signal generated by the infrared detector is converted to temperature signal and the necessary corrections between the emission surface, optical path and detector are performed by the model.

Key words: Infrared Radiation Thermometer, Laser Flash Method, Thermal Diffusivity

1. Introduction

The determination of thermal diffusivity by Flash Laser method [1,2] is based on the variation of temperature on the opposite side of a thin cylindrical sample result of a short pulse of energy received on its front side. The result of this increase in temperature is obtained from a thermogram and the thermal diffusivity is calculated as a function of sample thickness and the time required to reach half of the maximum rate of temperature on the opposite side. The improvement of the measurement method by developing a system to temperature measurement by infrared radiation with a response time of the order of nanoseconds and wide measurement range has become a priority to improve the quality of results for the Laboratório de Medição de Propriedades termofísicas (LMPT) of Centro de Desenvolvimento da Tecnologia Nuclear [3,4] (figure 1).

This work presents an innovative procedure for measuring the temperature applied to the measurement of thermal diffusivity. The mathematical modeling of this system is shown below as well as its computational implementation.

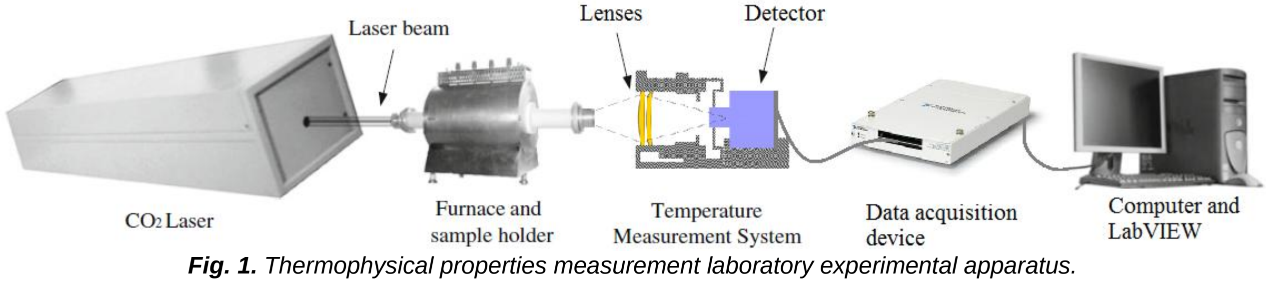

Fig. 1. *Thermophysical properties measurement laboratory experimental apparatus.*

2. Mathematical model

The temperature measurement system has been divided into two phases. The first phase is related with the project which involved the design and construction of the system. The HgCdTe detector is a photoconductive element which undergoes a change in resistance proportional to the incident infrared radiation. It is mounted in the metal dewar with ZnSe window and it offers optimum performance in the 8 to 12 µm. The second phase is related with the signal processing using LabVIEW. We used the J15D series HgCdTe detector and model PA-101 preamplifier voltage of the Teledyne Judson Technologies with the following characteristics:

HgCdTe detector	
Active area size:	4 mm^2
Cutoff wavelength (20 %)	> 12 µm
Peak wavelength	(11 ± 1)µm
Peak detectivity @ 10 kHz	min 1 x 10^{10} cm Hz ^{½} W^{-1}
	typical 1.5 x 10 10 cm Hz 1/1 W-1
Responsivity @peack	100 V/W
Time constant	0,5 µs
PA 101 preamplifier	
Bandwith	1 st stage 10Hz to 1 MHz 2nd stage 10 Hz to 200kHz
Gain	1 st stage 100x 2nd stage 10x
Input impedance	10kΩ through 100 µF capacitor
Input noise	1,5 nV Hz
Maximum Output level (high impedande load)	10 V p-p

In this initial configuration we selected ZnSe lens, a multifunctional board for acquisition and a microcomputer for signal processing using LabVIEW. The electrical signal corresponding to the radiation emitted from a blackbody, S_{bb} (T_{bb}) can described by [5]:

$$S_{bb}(T_{bb}) = g \cdot \frac{R^* \cdot A_d \cdot \tau_0}{4 \cdot F^2 + 1} \cdot \int_{\lambda_1}^{\lambda_2} M(T_{bb}, \lambda) \cdot s(\lambda) \cdot d\lambda. \tag{1}$$

Where g is the amplification of the electronic block, R^* is the peak detector spectral sensitivity given in V·W^{-1}, A_d is the detector area in cm^2, F represents the ratio of focal length of the lens and diameter of the objective, λ_1 and λ_2 are the limits of the spectral band of the detector in nm, M $(T,\ \lambda)$ is the spectral exitance at the temperature T and wavelength λ (W·m^{-2}·µm^{-1}), τ_0 is the transmittance of the lens used and s (λ) is the detector relative spectral detectivity function. The measuring signal, S_r (T) related to the temperature of any object under measurement conditions, can be expressed by [5, 6]:

$$S_r(T) = \ \varepsilon\tau S_{obj}(T) + (1-\varepsilon)\tau S_{refl}(T_{refl}) + (1-\tau)S_{env}(T_{env}) + S_{opt}\left(T_{opt}\right) + \Delta S \tag{2}$$

where S_{obj} (T) is the electrical signal corresponding to the radiation emitted by the object, ε is the effective emissivity of the object and τ is the effective transmissivity of the atmosphere. S_{refl} (T_{refl}) is the electrical signal corresponding to the radiation reflected from the surrounding objects, S_{env} (T_{env}) is the signal corresponding to the radiation emitted (or absorbed) by the environment between the object and the detector. S_{opt} (T_{opt}) is the electrical signal corresponding to the radiation emitted by the optical components and ΔS is the residual error (eg., size of source effect, drift of detector limited digital resolution). The temperature T_{out} of the object is calculated based on the value determined from the corrected signal S_r (T) converted to temperature using the calibration data. To verify the validity, reference samples of Pure Iron and Pyroceram 9606 were used.

3. Results

The mathematical model developed was implemented using the LabVIEW platform and its block diagram is shown in figure 2. The detector features, optical and geometrical properties, environmental influences and others parameters considered on the Eq. 1 and 2 are used as mathematical model settings as shown in figure 3.

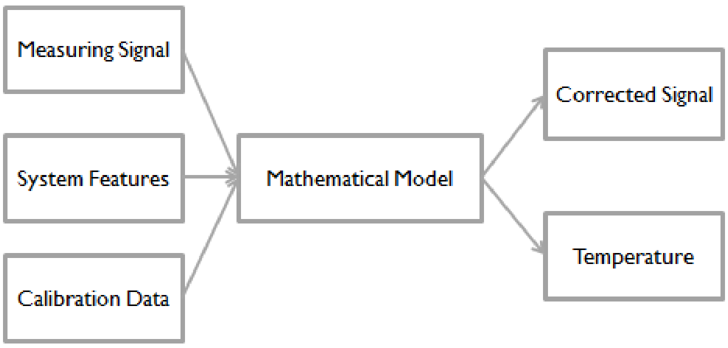

Fig. 2. *Block diagram of the application.*

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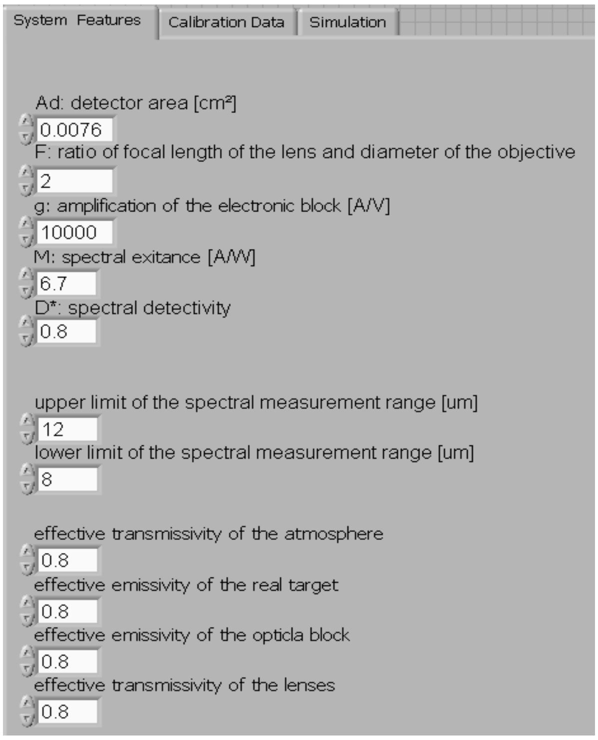

Fig. 3. *Mathematical model settings*

The measuring signal (S_{obj}) is acquired and corrections are performed according to the equation (2) to obtain the electrical signal corresponding to the radiation emitted by the object (S_r). The figure 4 shows those signals considering a typical Laser Flash measurement.

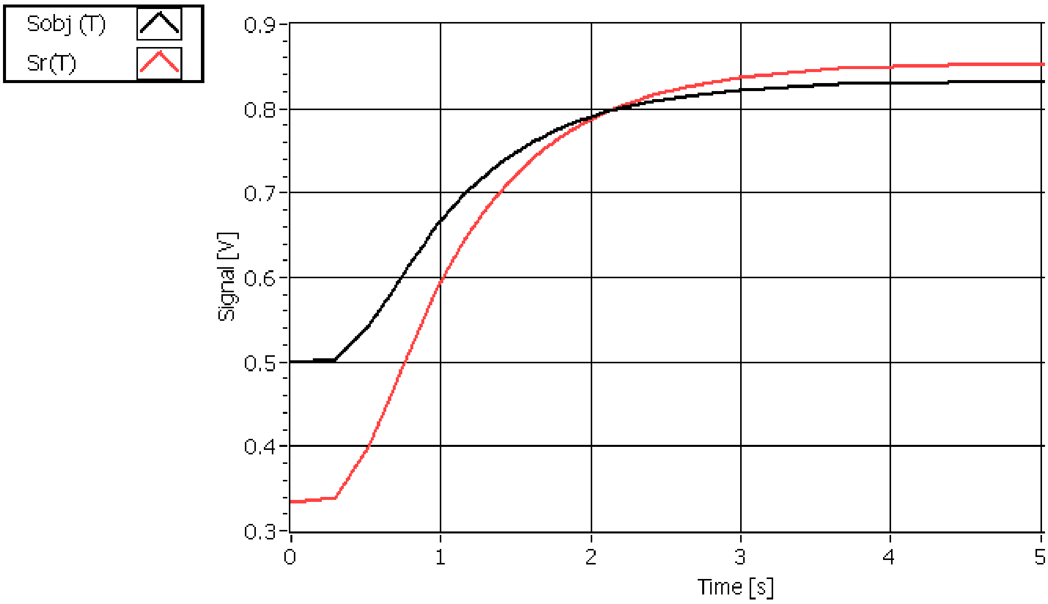

Fig. 4. *Typical signals obtained from Laser Flash measurements: S_{obj} and (S_r).*

In order to obtain the temperature values of the object under measurement a calibration curve must be obtained based on a calibration process using an ideal blackbody. The output temperature T_{out} is calculated on the basis of the determined value of the corrected signal S_r and calibration curve as shown in figure 5.

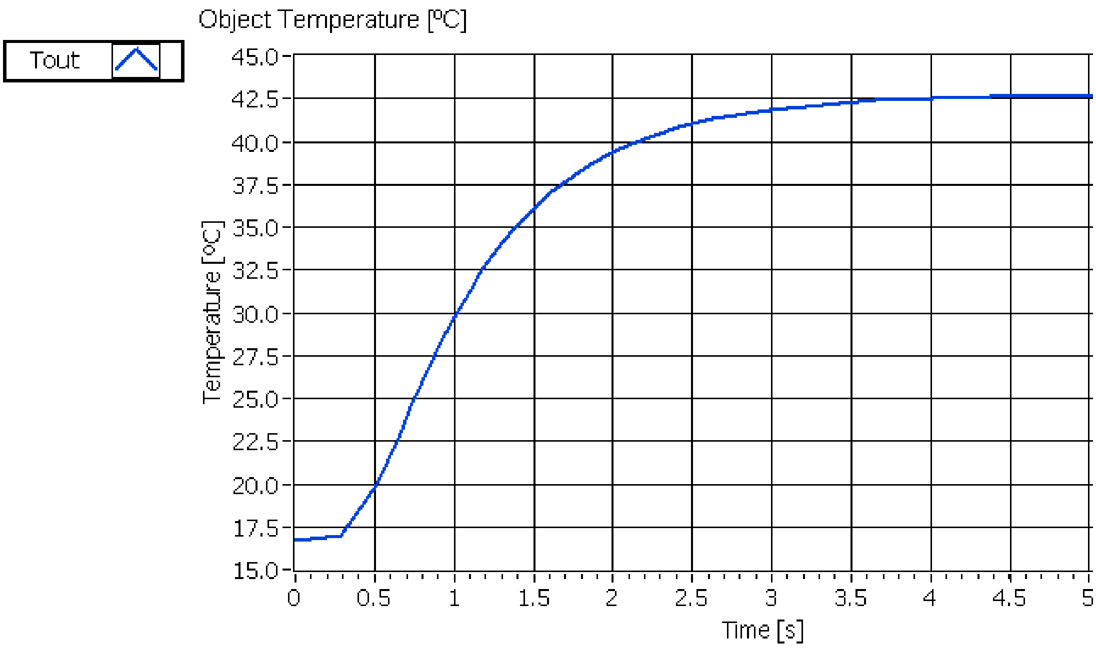

Fig. 5. *Typical temperature signal obtained from Laser Flash measurements.*

4. Conclusions

In this paper we presented a new system for measuring temperature with low response time coupled to the system for determination of thermal diffusivity using the flash method. The mathematical model was developed and implemented in *LabVIEW* platform for signal processing, correction and conversion of electrical signal corrected for temperature. The results show great potential for use in imaging systems used in thermal imagers, relatively low cost and adequate accuracy depending on the characteristics required for specific measurement systems with low thermal inertia and wide measurement range.

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