

New infrared radiation temperature measurement system applied to the Laser Flash Method

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Abstract. The laser flash method is based on measuring the temperature transient. The effect of the thermal inertia of the temperature measurement system is not negligible and cannot be ignored due to the fast dynamics of the measured thermal transient. This paper presents the new infrared radiation temperature measurement system applied to the thermal diffusivity measurements based on the laser flash method. The developed system consists in a detector cooled in liquid nitrogen, collimating lenses and a mathematical modeling developed in LabView. As a result, the generated electrical signal is converted into temperature. A detailed description of this new temperature measurement system is presented, as well as its mathematical model, computational implementation and calibration. For validate the new system, reference samples of homogeneous materials (Pyroceram 9606 and Inconel 600) were tested and the results of thermal diffusivities were compared with its reference certificates. The thermal diffusivity values measured by using the new system are in agreement with reference values, with less than 2 % of relative deviation.

1. Introduction

The determination of thermal diffusivity by laser flash method [1-4] is based on the variation of temperature on the opposite side of a thin cylindrical sample resulting from a short pulse of radiant energy received on its front side. This thermogram is measured 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 Laboratório de Medição de Propriedades termofísicas (LMPT) of the Centro de Desenvolvimento da Tecnologia Nuclear (CDTN/CNEN) is expanding the measurement capabilities of its metrological platform devoted to the determination of the main thermophysical properties of materials. Then, the development of new temperature measurement system with a response time of nanoseconds is a priority to improve the quality of the thermal diffusivity measurement of materials. The new temperature measurement system was designed and built to improve experimental apparatus used to determined thermal diffusivity. The mathematical modelling of this system is also presented on this paper as well as its computational implementation and calibration. Reference samples of homogeneous materials (Pyroceram 9606 and Inconel 600) were



used during the validation process and the results of thermal diffusivities were compared with its reference certificates.

2. Experimental apparatus and procedure

2.1. Physical design and construction

The design of the temperature measurement system has been divided into two phases. The first phase is related to the design and construction of the system. The HgCdTe detector is the photoconductive element which undergoes a change in resistance proportional to the incident infrared radiation. It is mounted in the metal dewar with ZnSe window offering optimum performance in the 8 to 12 μm . It was used the J15D series HgCdTe detector and the preamplifier model PA-101 supplied by Teledyne Judson Technologies. The ZnSe lens are the optical system used to collect the infrared radiation emitted by the sample. The system is equipped with an LED pilot light for accurate alignment of the sensor with the object to be measured. The signal is digitized using a 16 bits A/D converter of an NI PCI-6052 data acquisition device. The second phase is related with the signal processing using LabVIEW. Table 1 summarizes technical data of HgCdTe and the preamplifier used in the system. Figure 1 shows an overview of the new temperature measurement system.

Table 1. Summary of technical data of detector and preamplifier.

Item	Technical data
HgCdTe Detector	
Active area size:	4 mm ²
Cutoff wavelength (20 %)	> 12 μm
Peak wavelength	(11 $\pm$ 1) μm
Peak detectivity @ 10 kHz	min 1 x 10 ¹⁰ cm Hz ^{1/2} .W ⁻¹ typical 1.5 x 10 ¹⁰ cm Hz ^{1/2} .W ⁻¹
Responsivity @peak	100 V/W
Time constant	0.5 μs
PA 101 Preamplifier	
Bandwith	t1 stage 10 Hz to 1 MHz 2nd stage 10 Hz to 200 kHz
Gain	1 st stage 100x 2nd stage 10x
Input impedance	10 k Ω through 100 μF capacitor
Input noise	1.5 nV Hz
Maximum Output level (high impedance load)	10 V p-p

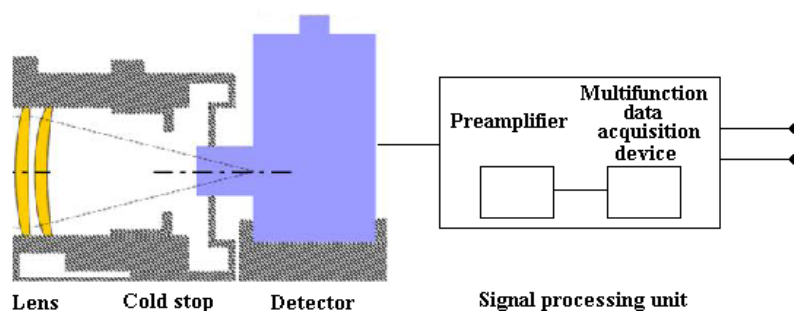


Figure 1. Structure of the new temperature measurement system.

2.2. Mathematical model

The electrical signal corresponding to the radiation emitted from a blackbody, $S_{bb}(T_{bb})$ is described by [5]:

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

Where g is the amplification of the electronic block, R^* is the peak detector spectral sensitivity given in $V \cdot W^{-1}$, 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 ($W \cdot m^{-2} \cdot \mu m^{-1}$), τ_0 is the transmittance of the lens used and $s(\lambda)$ is the detector relative spectral detectivity function. The measuring signal, $S_r(T)$ related to the temperature of any object is expressed by [5,6]:

$$S_r = \varepsilon \tau S_{obj}(T) + (1 - \varepsilon) \tau S_{refl}(T_{refl}) + (1 - \tau) S_{env}(T_{env}) - (1 - \tau) S_{opt}(T_{opt}) - S_{det}(T_{det}) \quad (2)$$

Where $S_{obj}(T)$, ε , τ is the electrical signal corresponding to the radiation emitted by the object, the effective emissivity of the real target and the effective transmissivity of the atmosphere, respectively. $S_{refl}(T_{refl})$ 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 $S_{det}(T_{det})$ is the electrical signal caused by the detector itself. 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 (figure 2).

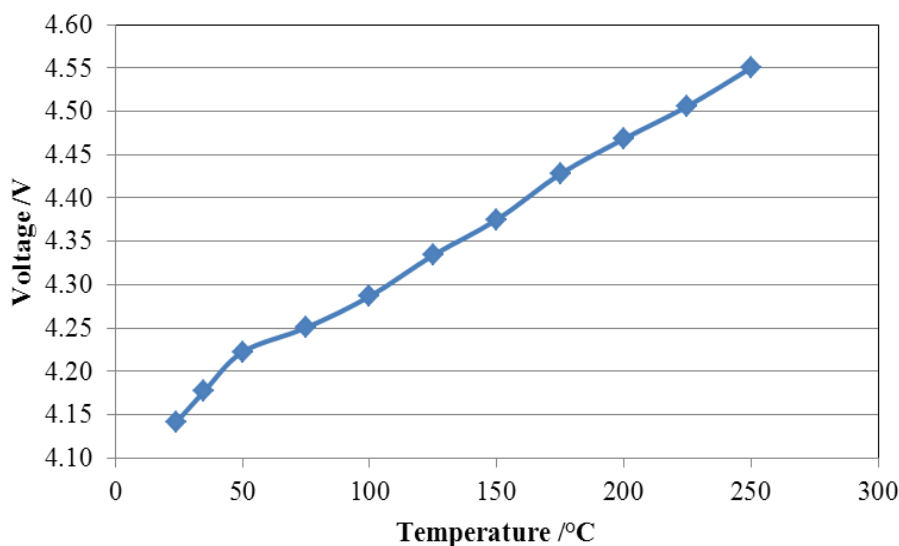


Figure 2. Calibration curve.

The mathematical model developed was implemented using the LabVIEW platform. The signal data are acquired and processed and the corrections are performed according to the equations described above. The corrected electrical signal is converted to temperature signal, considering the calibration of the system (figure 3). The program generates a screen containing the signal graph in temperature over time (figure 4).

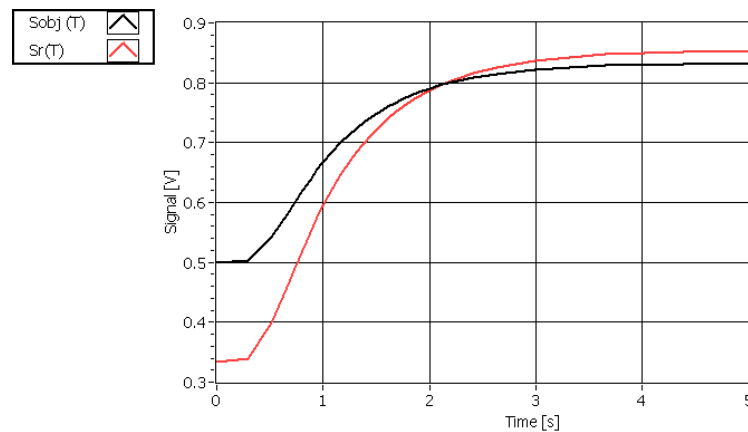


Figure 3. Typical signals obtained from laser flash measurements: S_{obj} and S_r .

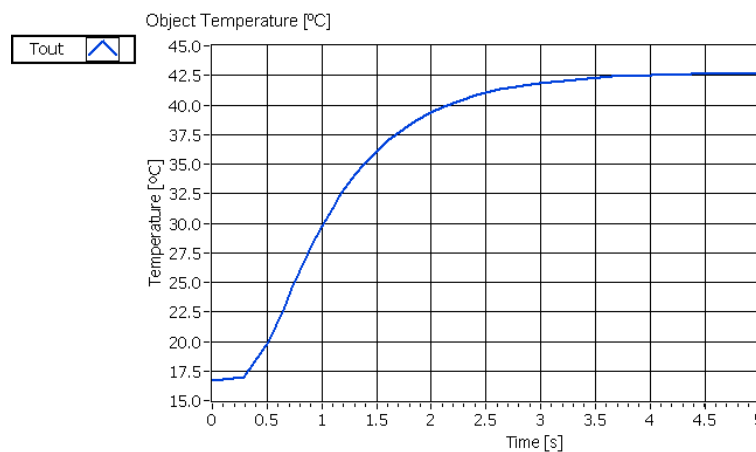


Figure 4. Typical temperature signal obtained from laser flash measurements.

2.3. Thermal diffusivity measurement

To verify the validity and desired features of the new temperature measurement system, it was used to measure the thermal diffusivity of two reference samples (Pure Inconel 600 and Pyroceram 9606) using the laser flash method [1-4]. The system was coupled to the apparatus [4] developed by the staff of the Laboratório de Medição de Propriedades Termofísicas of Centro de Desenvolvimento da Tecnologia Nuclear (figure 5). This apparatus is composed of sample holding device, heating furnace, laser CO₂ (of 100 W total power) working at 10.6 μm wavelength, vacuum pump, measuring control and data processing system. The thermal radiance signal is digitized using a 16 bits A/D converter of an NI PCI-6052 data acquisition device and a LabView programming is used to acquire data. A thin carbon layer was applied over the front surfaces of the samples (8 mm in diameter and about 2.5 mm thickness). The rear surfaces of the samples were also coated to ensure an uniform emissivity.

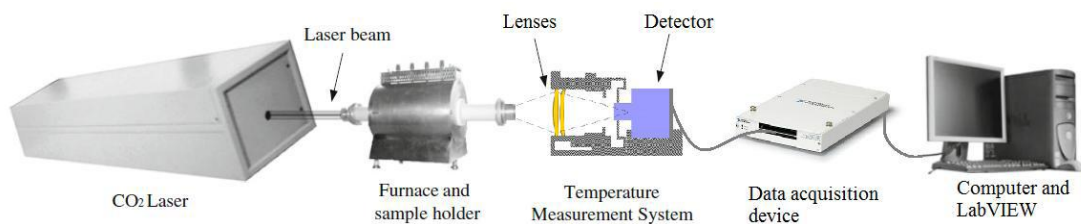


Figure 5. Schematic of the experimental apparatus for thermophysical properties measurements.

3. Results

All thermal diffusivity values presented hereafter result from the average of successive measurements carried out on repeatability conditions. The results obtained for the thermal diffusivity of Inconel 600 and Pyroceram 9606 standard samples are shown in table 2. The results show good agreement with the reference values of both samples. The maximum deviation of obtained values for thermal diffusivity using the new temperature measurement system from the certificated value is in less than 2 %, which is within the uncertainty of the value estimated in 7.5 %. The uncertainty assessment of the experimental apparatus [7] is performed in accordance with the ISO Guide to the Uncertainty in Measurement (GUM) [8]. The uncertainty of the certified thermal diffusivity values are 7.5 % at the 95 % confidence level [9].

Table 2. Thermal diffusivity of reference samples at room temperature.

Thermal diffusivity / $\text{mm}^2 \cdot \text{s}^{-1}$		
Reference sample	Mean value	Reference value [9]
Pyroceram 9606	2.02	2.02
Inconel 600	3.42	3.44

4. Conclusions

In this paper was 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 to temperature signal. The results show great potential for use in thermal imaging systems with relatively low cost and adequate accuracy, with low thermal inertia and wide measurement range. Experiments carried out with reference samples demonstrated good agreement between the reference and obtained values, with a relative deviation of less than 2 %. A more detailed investigation becomes necessary to for a better evaluation of the reproducibility of the system using others reference samples.

Acknowledgments

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