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SPECTRAL RESPONSIVITY CALIBRATION OF THE LINEAR PYROMETER OF INMETRO

Maurício Simões Lima [1], *Renato Nunes Teixeira* [2], *Augusto Poças Cunha*[1], *Iakyra Borrakuens Couceiro* [1]

[1] Inmetro / Diopt, Duque de Caxias, Brazil, mslima@inmetro.gov.br
[2] Inmetro / Diter, Duque de Caxias, Brazil, rnteixeira@inmetro.gov.br

Abstract: This paper describes in detail the spectral responsivity calibration of the Linear Pyrometer of the Thermal Metrology Division (Diter) of Inmetro. This calibration was performed at the Radiometry Laboratory (Larad) of the Optical Metrology Division (Diopt). It was made using two different experimental setups. In the first one, mirrors were used to direct the radiation beam from the exit slit of the monochromator to the entrance of the detectors. In the second setup the detectors were aligned directly in the exit slit of the monochromator. The spectral responsivity values in the first setup were lower than the second one. The uncertainty evaluation was performed for the second configuration data. The characterisation process of the linear pyrometer, will allow the maintenance of the International Temperature Scale of 1990 (ITS-90) on the instrument itself.

Keywords: radiometry, pyrometry, spectral responsivity

1. INTRODUCTION

In the higher portion of the International Temperature Scale of 1990 (ITS-90) – above 962°C, there are at least three different operational schemes to maintain the scale [1]. A) The fixed-point calibration is transferred to a reference tungsten strip lamp. Different temperatures are established and maintained on the lamp by measurement of radiance ratios. B) The fixed-point calibration is transferred to a reference tungsten strip lamp. Temperature T_{90} of any source is determined according to the defining equation of the ITS-90 by measuring the signal ratios between the source and the reference lamp at the fixed-point temperature. C) The fixed-point calibration is maintained on the thermometer. The output signal is assumed to be representative of T_{90}.

At Inmetro, it was decided to maintain the ITS-90 on the thermometer, which is a single cell silicon detector pyrometer, model LP3, manufactured by KE, Germany. In order to have confidence in the instrument, it is necessary to calibrate the pyrometer in spectral responsivity, assess the size-of-source effect and verify the non-linearity of the instrument. This work describes the calibration of the LP3 on spectral responsivity, using a trap detector as a reference standard.

Silicon trap detectors are very convenient as transfer standard in modern radiometry [2,3]. They have many advantages compared with single photodiode, as a spectral responsivity stable in time, excellent homogeneity of response across the aperture, good linear response and a short time constant. The pyrometer calibrated has two interference filters, one centered at 650 nm and the other centered at 900 nm.

The measurements were performed scanning wavelengths of 20 nm around the centered values (650 nm and 900 nm). Despite of that, a broad scan was also performed to verify the existence of out-of-band transmittance.

2. EXPERIMENTAL SETUP

A tungsten halogen lamp was used as source and placed at 600 mm of the entrance slit of a single grating monochromator. The monochromator has one holographic plane grating with 1200 gr/mm. The spectral range of this grating is from 400 nm to 1300 nm. The measurements were made using a digital multimeter with resolution of 6 ½ digits and an amplifier of the electrical signal. The measurements were performed automatically through self-made software, which also controlled the shutter, translation stage and monochromator operations.

The beam size at the entrance of the trap detector was approximately 6 mm at 650 nm and 3 mm at 900 nm, using an iris as aperture. Cut-off filters were installed close to the entrance of monochromator to eliminate second order diffraction and minimise stray light.

The calibration of the pyrometer used as reference a reflection trap detector with three photocells, calibrated at Inmetro.

The calibration of the monochromator was performed using spectral lamps.

The measurements were performed in two different setups, because it was verified that there is not a consensus among the National Metrology Institutes (NMIs) on how to perform such a calibration. In the first setup, the objective lenses of the pyrometer were removed and the radiation overfilled the LP3 aperture. In this case, the entrance and exit slits of the monochromator were set to 0.125mm. In the second setup, all the measurements were performed with all lenses that are normally used in the pyrometer. In this configuration, the slits were set to 0.6mm. Figures 1 and 2 show the experimental setup used to calibrate the linear pyrometer. It was necessary to choose the best configuration to make the measurements of the spectral responsivity, taking into account the signal-to-noise ratio. After analysing the data, the second setup presented the best performance. In this case, the results of the pyrometer calibration were closer to the values found on literature [1]. This approach is also more representative of the normal utilization of the instrument, that is, using its imaging optics.

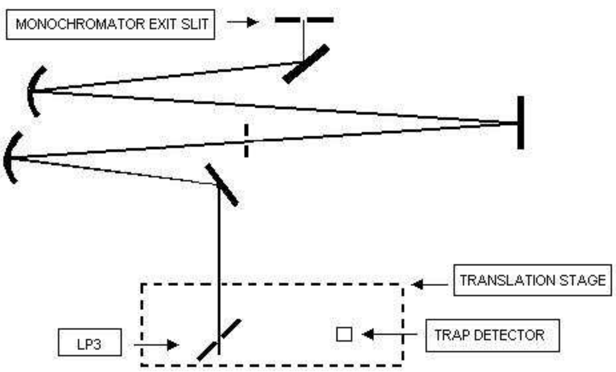

Figure 1. First experimental setup

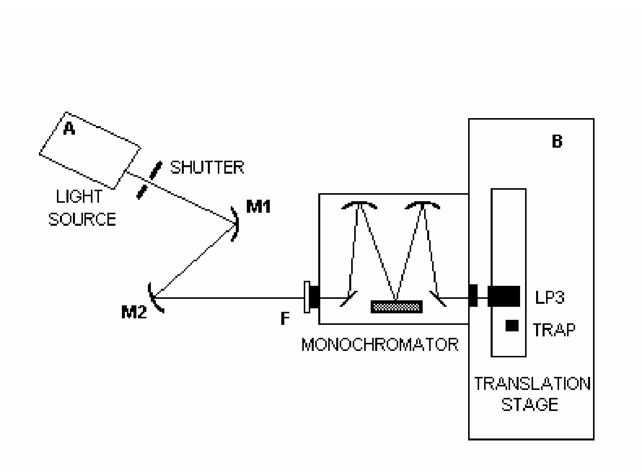

Figure 2. Second experimental setup

2.1 Theoretical background

The spectral responsivity of a radiation detector may be obtained by equation 1[5]:

$$S_t = \frac{I_t}{I_r} \cdot \frac{G_r}{G_t} \cdot S_r \qquad (1)$$

where $\boldsymbol{S_t}$ is the responsivity of the test detector, $\boldsymbol{I_t}$ is the electrical signal of the test detector, $\boldsymbol{I_r}$ is the electrical signal of the reference detector and $\boldsymbol{S_r}$ is the responsivity of the reference detector.

2.2 Results and Discussion

Figure 3 shows the spectral responsivity curves of the pyrometer in the spectral range from 640 nm to 670 nm.

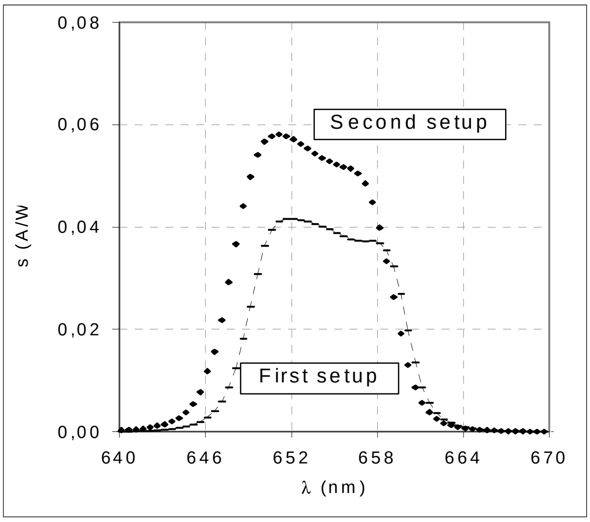

Fig.ure 3. Responsivity spectral curves of the LP3 - 650 nm.

Figure 4 shows the spectral responsivity curves of the pyrometer in the spectral range from 890 nm to 920 nm.

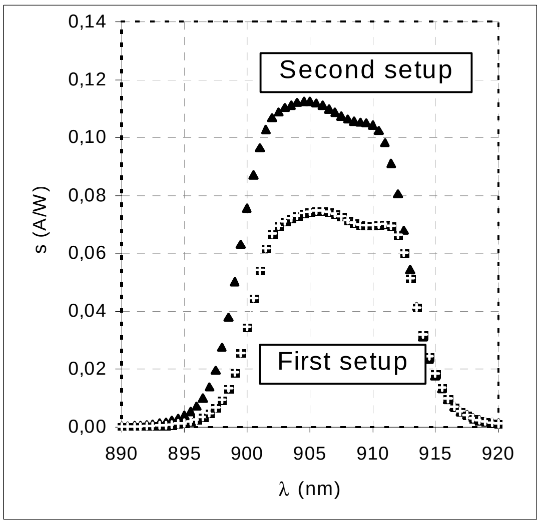

Fig.ure 4. Responsivity spectral curves of the LP3 - 900 nm.

It is observed in the Figure 3 that the measurements realized in the setup 2, shown in the Figure 2, present better results than the measurements realized in the setup shown in Figure 1, when compared to the results presented in the literature of this subject [1].

The uncertainty evaluation was made for the measurements of the second setup. It took into account the contribution of the reference detector calibration, the monochromator calibration, repeatability of the measurements, the resolution of the monochromator, drift of the reference and calibration of electronic instruments.

It can be seen in table 1 the influence quantities and their uncertainty contributions, in the wavelength range from 630 nm to 675 nm, in the spectral responsivity calibration of pyrometer LP3 of Inmetro. The expanded standard uncertainty for this spectral range is 1.2 %, at 95.45% (k=2) confidence level.

Table 1. Uncertainty evaluation for 650 nm interference filter

Quantity (X_i)	**Standard uncertainty** $u(x_i)$ **(%)**
Standard deviation of the reference detector	0.0012
Reference detector calibration	0.55
Drift of the reference detector	0.1
Electronic system	0.011
Standard deviation of pyrometer	0.0052
Monochromator calibration	3.4E-07
Monochromator resolution	0.0088
Ambient conditions	0.0001
Expanded standard uncertainty	**1.2**

Table 2 shows the uncertainty evaluation for the range 880 nm to 910 nm. In this case, the expanded standard uncertainty found was 1.1 %, with k=2. Like the previous spectral range, the major contributions of uncertainty are again the reference detector and its drift.

Table 2. Uncertainty evaluation for 900 nm interference filter

Quantity (X_i)	**Standard uncertainty** $u(x_i)$ **(%)**
Standard deviation of the reference detector	0.0012
Reference detector calibration	0.43
Drift of the reference detector	0.35
Electronic system	0.011
Standard deviation of pyrometer	0.0042
Monochromator calibration	1.3E-07
Monochromator resolution	0.0064
Ambient conditions	0.0001
Expanded standard uncertainty	**1.1**

Figure 5 shows several measurements of responsivity in the spectral range from 640 nm to 670 nm. It can be seen the reproducibility of the measurements, however there are differences between the curves heights, probably due to misalignment of the experimental setup but the profile of the curves are similar. For the spectral range from 880 nm to 920 nm, not shown, the behaviour of the curve was the same.

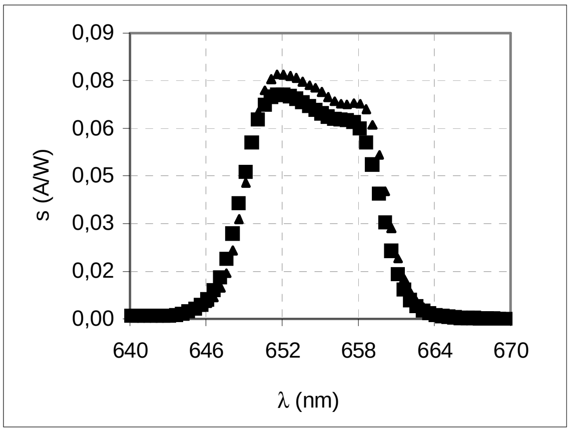

Figure 5. Reproducibility of responsivity spectral of the pyrometer in the range 640 nm to 670 nm.

Figures 6 and 7 show the electrical response of the pyrometer outside the wavelength range of interest, in order to verify the existence of out-of-band transmittance in the filters. Undesirable peaks were not detected either in the 650 nm or in the 900 nm filters, for the wavelength range scanned.

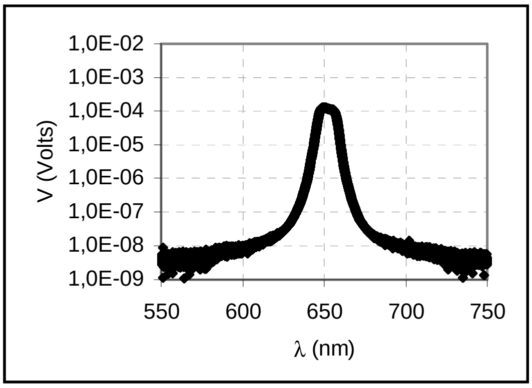

Figure 6. Electrical signal of the LP3 – 650 nm scan.

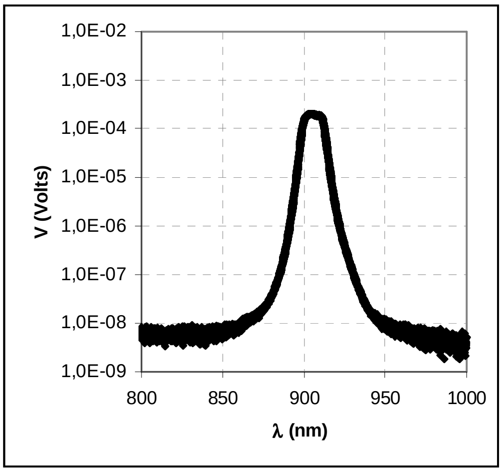

Figure 7. Electrical signal of the LP3 - 900 nm scan

3. CONCLUSION

This is the first step to full characterise the linear pyrometer of Inmetro. In order to maintain the ITS-90 on the instrument, it will also be necessary to check the linearity of the detector and assess the size of source effect (SSE) of this device.

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