FINAL REPORT EUROMET PROJECT 741

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Jean BASTIE, Mihai SIMIONESCU

1. Introduction

Before 2002 INM, Romania (INM) used to maintain the units of luminous intensity and luminous flux with groups of standard lamps, calibrated by the BIPM laboratory. Following the decision to stop the calibration of such standard lamps at BIPM, INM decided to proceed to the development of new reference standards, based on the definition of candela and according to the CIPM recommendations **[1, 2, 3]**.

During 2003, a bilateral EUROMET co-operation project, between LNE, France (LNE) and INM, Romania (INM) was undertook aiming at :

a) development of the INM instrument and skills to realise the candela based on narrow band spectral measurements, according to the CIPM recommendations and
b) first preliminary validation of the newly developed (absolute) photometer and the INM method for the candela realization.

2. Organization

The main stages of the project were as it follows :

2.1 Absolute photometer (FA 02) development at INM : 2003;
2.2 FA 02 photometer characterization at INM : 2004 ;
2.3 Validation of the FA 02 photometer and method : 2004 to 2006.

2.1 Absolute photometer development at INM-Romania : principle and design

2.1.1 Principle

Basically, the luminous intensity of an unknown source measured with an absolute photometer is :

$$I_v = \frac{d^2}{s_v} \cdot i_{ph} \qquad \textbf{(1)}$$

where : d is the lamp-photometer distance (m);
i_{ph} is the photometric current (A);
s_v , the luminous responsivity of the photometer (A/lx) computed with :

$$s_v = \frac{A \cdot s_m}{K_m \cdot F} \qquad \textbf{(2)}$$

with : A the effective area of the photometer aperture (m^2);
s_m the peak absolute, spectral responsivity of the photometer (A/W);

K_m the maximum luminous efficacy of the CIE standard observer (683 lm/W);
F the spectral matching factor, computed according to :

$$F = \frac{\int S(\lambda) \cdot V(\lambda) \cdot d\lambda}{\int S(\lambda) \cdot s_r(\lambda) d\lambda} \quad \textbf{(3)}$$

with: $S(\lambda)$ - the relative spectral density of the lamp emitted flux;
$V(\lambda)$ - the relative luminous efficacy function of the **CIE** standard observer **[4, 5]**;
$s_r(\lambda)$ - the relative spectral responsivity of the photometer.

2.1.2 Design

The FA 02 absolute photometer consisted of a V(λ) filtered trap detector **[6]** and a dc current to voltage converter providing a very low input impedance (see Fig. 1).

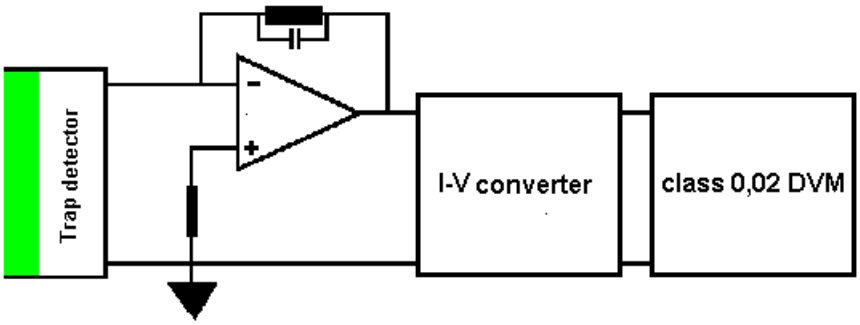

Fig. 1 - The FA 02 photometer (schematic)

The V(λ) filtered trap detector was based on the CL 01 trap detector previously developed by INM and calibrated by LNE with traceability to the LNE primary reference, a cryogenic radiometer [7]. CL 01 (without any filter) was also used as the INM reference standard for spectral responsivity measurements.

The V(λ) correcting filter was of a sandwich type. Four coloured glasses were used. The corresponding thickness were computer assisted designed using the spectral responsivity of the unfiltered trap as input data.

For candela realization, a circular, precision aperture was placed in front of the correcting filter (see Fig. 1). It was removable in order to avoid vignetting during the spectral responsivity characterisation of the FA 02.

2.2 FA 02 photometer characterization at INM

Following some partial characterization tests for electric and photometric linearity the new photometer was characterised as a whole against the reference trap detector **CL 01**, traceable to the LNE spectral responsivity primary reference, a cryogenic radiometer.

2.2.1 Spectral responsivity characterization

At INM, a spectro-radiometric comparator consisting of a source, a monochromator, conditioning optics and a translation stage was used in order to implement the direct substitution

method. Basically, the filtered trap, FA 02)was compared to the CL 01 by simply switching the V(λ) correcting filter in and of the comparison beam.

A focused beam f/11 was used throughout. It was focused at the level of the second photodiode of the trap detector. The measuring spot was of a 4 mm diameter thus under filling the FA 02 measuring aperture. However, during this stage, the precision area aperture was used only for alignment purposes and then removed in order to avoid vignetting.

2.2.2 Measurement area estimation

The measuring aperture actual area was estimated by direct measurement of its diameter on an Abbe comparator. Six directions of the diameter were used.

2.2.3 INM estimation of the FA 02 luminous responsivity and associated uncertainty

Considering (2) and the imperfect photometric linearity, the luminous responsivity of the FA 02 photometer is :

$$s_v = \frac{A \cdot s_m}{K_m \cdot F} \cdot C_{lin} \qquad \textbf{(2a)}$$

where C_{lin} is a correction factor for the photometer linearity.

The s_v value, computed according to **(1)** was :

$$s_{v(INM)} = 9{,}568 \ \ nA/lx$$

This associated uncertainty value is detailed in **Tab. 1.**

Tab. 1.- FA 02 luminous responsivity ; the associated uncertainty budget

Quantity	Type	Source of uncertainty	$u(x_i)$	c_i	Probab. distrib.	$c_i \cdot u(x_i)$ [nA/lx]	Deg. of freedom
F	B	Matching factor	$3.09*10^{-3}$ (one)	$8.76*10^{-9}$ A/lx	Normal	0.0271	∞
s_m	B	Peak responsivity	$4.38*10^{-4}$ A/W	$3.71*10^{-8}$ W/lx	Normal	0.0162	∞
A	B	Photometer aperture area	$2.8*10^{-8}$ m^2	$2.32*10^{-4}$ $A/(lx*m^2)$	Normal	0.00649	∞
C_{lin}	B	FA 02 Non-linearity corr. factor.	0.001 (one)	6.50E-09 (A/lx)	Normal	0.0065	∞
Combined standard uncertainty						**0.033 [nA/lx]**	
						0.49 [%]	

2.3 Validation of the FA 02 photometer and method

After calibration at INM, the FA 02 was calibrated again by LNE in terms of luminous responsivity. This calibration was performed against two standard lamps that participated to the latest CCPR relevant key comparison. The optical distance of measurement was 2.979 m. The LNE results are given in **Tab. 3**.

Table 3 – Calibration of the photometer FA-02 using standard lamps (LNE values)

Lamp serial	Luminous intensity [cd]	Illuminance [lx]	FA 02 Photo-current [A]	FA 02 luminous responsivity [A/lux]
A 430	395.7	44.603	$4.2681\ 10^{-07}$	$9.5691\ 10^{-09}$
A 431	390.0	43.960	$4.2253\ 10^{-07}$	$9.6117\ 10^{-09}$
			Mean	$9.590\ 10^{-09}$
			Rel. standard deviation	$3.1\ 10^{-03}$

The LNE measurement uncertainty budget is given in **Tab. 4.**

Tab. 4 LNE relative associated uncertainty to measurement results

LNE candela realization:	
Photometric scale	0.43 %
Geometrical conditions :	
Lamp-FA 02 measuring aperture distance :(x2)	0.05 %
Current generated by the FA 02 photometer:	
Current to voltage converter :	0.04 %
Measured voltage :	0.005 %
Lamps supply :	
Current trough the lamp filament :	0.005 %
Shunt resistance :	0.06 %
Measurement repetability :	
Standard deviation :	0.15 %
LNE combined standard uncertainty (1σ) as computed by quadratic sum :	**0.46 %**

3. Discussion.

3.1 Comparison of the results of INM to the results of LNE

The INM estimated value of the FA 02 luminous responsivity was :

$$S_{v(FA\ 02,\ INM)} = 9.568 \text{ +/- } 0.047 \text{ nA/lx}$$

At LNE, the luminous responsivity of the FA 02 photometer was measured to be:

$$S_{v(FA\ 02,\ LNE)} = 9.590 \text{ +/- } 0.044 \text{ nA/lx}$$

The stated uncertainties are standard uncertainty (k=1)

Therefore, the relative difference between the two laboratories was :

$$\Delta s_v = 2.3\ 10^{-3}$$

The relative standard uncertainty associated to this difference was :

$$U_{\Delta s} = 6.7\ 10^{-3}$$

3.2 Comparison of the results of INM to the results of CCPR-K3.a

The results of the CCPR-K3a key comparison as they are published in the BIPM database shows that the luminous intensity of the standard lamps of LNE is higher than the reference value of the comparison by 0.89 % with an associated uncertainty of 0.60 % [8, 9]. So, using these information and considering that the lamps have maintained their calibration, it is possible to determine the deviation of the results of INM versus the reference value of the CCPR-K3a key comparison. For that, the luminous intensity assigned to the lamps used for the measurements and which have participated in the CCPR-K3a comparison, was reduced by 0.89 % and the calculation were repeated. The results of these new calculations are given in table 5.

Table 5 – Calibration of the photometer FA-02 using standard lamps (CCPR-K3a values)

Lamp serial	Luminous intensity [cd]	Illuminance [lx]	FA 02 Photo-current [A]	FA 02 luminous responsivity [A/lux]
A 430	392.2	44.208	$4{,}2681\ 10^{-07}$	$9.6546\ 10^{-09}$
A 431	386.5	43.566	$4{,}2253\ 10^{-07}$	$9.6986\ 10^{-09}$
			Mean	$9.677\ 10^{-09}$
			Rel. standard deviation	$3.2\ 10^{-03}$

As written previously, the INM estimated value of the FA 02 luminous responsivity was :

$$S_{v(FA\ 02,\ INM)} = 9.568 \text{ +/- } 0.047 \text{ nA/lx}$$

Therefore, the relative difference between INM and the CCPR-K3a reference value was :

$$\Delta s_v = 11.3\ 10^{-3}$$

And the relative standard uncertainty associated to this difference was :

$$U_{\Delta s} = 9.0\ 10^{-3}$$

4. Conclusion and further developments

Based on the results obtained and on the expertise gained within this cooperation project EUROMET 741, INM has developed several new photometers based on V(λ) corrected trap detector. The methods for charactering the photometers have also been improved and the final realisation of the candela at INM has been implemented.

In order to support the CMC claimed by INM and based on the new realisation of the candela at the National Institute of Metrology of Romania, in 2005 LNE and INM agreed and undertook the comparison type project EUROMET 823. Actually, it concerned two supplementary comparisons linked to the CCPR K3a and CCPR K4 key comparisons. The measurements were completed during 2006 and the final reports of both comparisons are in progress.

References

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