Recalibration of working standard lamps

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Abstract: In the present work, recalibration of the National Institute for Standards (NIS, Egypt) working standard lamps from Osram Inc. and their associated expanded uncertainty budget were done. A set-up composed of an integrating sphere, a standard photometer and a group of five luminous flux standard lamps ranged from 25 to 200 W calibrated and traceable to the National Physical Laboratory (NPL, UK) is used to measure and recalibrate the total luminous flux for these five working standard lamps. After recalibration, NIS (Egypt) maintains the national scales for luminous flux in lumen.

Key words: luminous flux; working standard lamps; standard photomer; integrating sphere

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Luminous flux is a key parameter for some inspection organizations and industrial laboratories in Egypt. The integrating sphere is a device to measure total luminous flux for any light source and its function is to spatially integrate radiant flux. When light incident on a diffuse surface creates a virtual light source by reflection, the detector at any point on the surface can measure the total power in the entire sphere.

National Institute for Standards (NIS) photometric department provides them with luminous flux working standards for incandescent lamps. These lamps are used as standard to calibrate the integrating spheres in these industry laboratories. The lamps are 25, 40, 75, 100 and 200 W, respectively. These types of lamps are available in our study of lamp operation, screening and seasoning. Incandescent standard lamps for luminous flux are IEC2005, IEC2008 and IEC1995[1-3], without seasoning to these lamps because we do recalibration. Luminous flux standard lamps are normally operated in the base-up position, and seasoning should be conducted in the same burning position. Standard lamps are screened for aging rate, reproducibility and storage stability in a similar manner as luminous intensity standard. Aging characteristics vary largely depending on the type of lamp and operating color temperature. Traditionally, luminous flux lamps have been designed and used at color temperatures of 2 700 K to 2 800 K in order to reduce the aging rate. Linear fluorescent lamps are normally seasoned for 750 h and screened for reproducibility. It is obvious that the investigated lamps are sensitive to burning position. The lamps are always operated at the base-up vertical position. The lamps should be operated on DC power supply at different voltages. As the luminous flux of the lamps changes significantly with ambient temperature, which must be controlled within 25°±1° before starting the measurements and the lamps should be stabilized for 10 min. with integrating sphere open. The present work depends on Illuminating Engineering Society (IES) guide[1].

1 Experimental set-up

1.1 Measurement set-up of luminous flux for lamps

Fig. 1 shows the NIS integrating sphere photometer system with 2.5 m integrating sphere in the routine calibration setting. The integrating sphere is equipped with $V(\lambda)$-corrected filter, cosine-corrected

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detector, a baffle screen, auxiliary lamp, a temperature sensor and spectroadiometer. The $V(\lambda)$-corrected detector is LMT standard photometers equipped with opal glass diffuser and it has a linear response with range of 16—28 nA/lx. Based on these characteristics, the total luminous flux from 0.01—106 lm can be measured in direct substitution with total luminous flux standard lamps of any wattage. The sphere wall is coated with barium sulfate paint with diffuse reflectance of approximately 0.98 in the visible region. The spectral throughput of the sphere is obtained by measuring the relative spectral irradiance of a tungsten lamp operated inside and outside the sphere with the spectroradiometer.

Fig. 1 NIS integrating sphere photometer system (diameter: 2.5 m)

The integrating sphere is also equipped with an auxiliary lamp (100 W tungsten) on the sphere wall to measure the self absorption effects of a lamp in the sphere. The room temperature of the photometry laboratory is controlled to be about 24 ℃. A temperature sensor is mounted to measure the air temperature of the area inside the sphere. During lamp operation the ambient temperature in the sphere is approximately 25 ℃[4].

1.2 Electrical facility

The electrical circuit for recalibration of working lamp measurement is shown in Fig. 2. The lamp is mounted in the base-up position. During photometric measurements the supply voltage V_1, the lamp current A_L, the lamp voltage V_L and the lamp power W_L are measured and recorded.

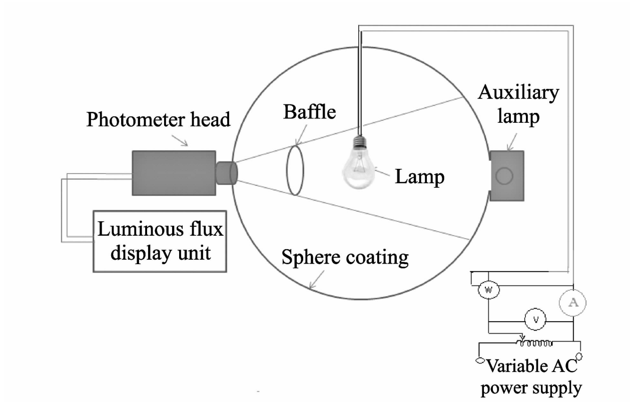

Fig. 2 NIS 2.5 m integrating sphere set-up for routine calibration

2 Luminous flux standard lamps

The results of luminous flux measurements carried out using the sphere photometer by the substitution principle will be correct if the light source to be measured and the luminous flux standard lamp used satisfy the conditions as follows[5-6]:

1) The same spectral distribution;
2) The same dimension and shape;
3) The same spatial light distribution.

If the light source to be measured and the standard lamp differ in one or more of these properties, measurement errors may occur. The influence of different spectral distributions can be eliminated by using the mismatch correction factor which depends on full details of the spectral response of the measuring equipment (including photometer head and sphere paint) and the spectral power distributions of the measured and the standard light source. A correction for the influence of different dimensions and shapes is possible by use of an auxiliary lamp to determine the self-absorption correction. It has been found that the most suitable standard lamps to recalibration of working standard lamps are 25 and 200 W primary standard lamps in NIS photometry lab.

3 Correction in measurements

For measuring luminous flux using sphere photometer, the following corrections must be carried out.

3.1 Spectral mismatch correction and its determination

The spectral mismatch correction factor ccf of each lamp type against the 300 W primary standard lamp is given by

$$ccf(S_t, S_s) = \frac{\int_\lambda S_s(\lambda) R_s(\lambda) d\lambda \int_\lambda S_t(\lambda) V(\lambda) d\lambda}{\int_\lambda S_s(\lambda) V(\lambda) d\lambda \int S_t(\lambda) R_s(\lambda) d\lambda}, \quad (1)$$

where $S_t(\lambda)$ and $S_s(\lambda)$ are the relative spectral power distributions of the tested and standard lamps, respectively; $V(\lambda)$ is the spectral luminous efficiency function and $R_s(\lambda)$ is the relative spectral responsivity of the sphere system. $R_s(\lambda)$ can be obtained by measuring the relative spectral responsivity of the detector $R_d(\lambda)$ and the relative spectral throughput of the integrating sphere $T_s(\lambda)$ using the following equation as

$$R_s(\lambda) = R_d(\lambda) T_s(\lambda), \quad (2)$$

where $T_s(\lambda)$ can be obtained by measuring the relative spectral irradiance of tungsten standard lamp operating inside the sphere and outside the sphere with spectroradiometer and dividing these values. From Eq. (1), it can be seen that the value of the $ccf(S_t, S_s)$ depends on $S_t(\lambda)$ and hence on correlated color temperature (CCT) of the calibrated lamps.

3.2 Self-absorption correction and its determination

We mean the self absorption correction by the ratio between the quantity of the absorbed light by the lamp and baffle inside the sphere in case of standard and tested lamps. The auxiliary lamp (100 W) is used for the three lamp types. To determine the self absorption correction, we do the following steps.

1) The standard lamp inside the sphere is switched off and the auxiliary lamp is lit. The reading of the photometer corresponding to the luminous flux of the auxiliary lamp and absorption for presence of standard lamp is measured as r_s.

2) The standard lamp is replaced by the lamp under test which is not switched on. The auxiliary lamp remains lit and the reading of the photometer corresponding to the luminous flux of the auxiliary lamp and absorption of the lamp under test is measured as r_t and hence the self-absorption will be equal to r_s/r_t.

3.3 Correction for sphere detector temperature

There is no error because the lamps have the same spectral distribution. The responsivity of the sphere detector slightly changes with its temperature and is monitored with a temperature sensor installed in the detector package. In order to avoid such error, the detector temperature must be controlled at its calibrated value.

It is worthwhile to note that the correction for the spatial nonuniformity of the sphere response is neglected as in this work the considered lamps have no reflector and hence have a regular spatial distribution[7].

4 Uncertainty budget in luminous flux measurements

The uncertainty factors arising in luminous flux measurement using sphere photometer are as follows.

1) Calibration of luminous flux standard lamp

The uncertainty of luminous standard lamp is stated in calibration report issued by a laboratory in international institutes. In this work the calibration is done in National Physical Laboratory (NPL) in England.

2) Aging of the standard lamp

This uncertainty measures the rate of luminous flux drift per hour and the interval between two calibrations (In this work the interval is 50 h).

3) Uncertainty due to self-absorption of 2σ

σ is standard deviation of the values of self-absorption correction factor.

4) Repeatability of test lamps

This uncertainty is calculated as two times the standard deviation σ of the three measurements for each lamp[8].

5) Uncertainty of mismatch factor correction

This uncertainty depends on the relation of ccf versus CCT and can be determined by multiplying the uncertainty of CCT of the tested lamp with the slope of ccf as function of CCT for such lamp[9-10].

5 Experiment

According to the above mentioned items, the experimental data needed to determine the uncertainty budget are as follows.

1) The determination of σ for self-absorption correction.

The self-absorption correction has been measured five times for each lamp types, accordingly the values of self-absorption corrections are illustrated in Table 1.

Table 1 σ for self-absorption correction for three lamp types

Lamps (W)	25	40	75	100	200
σ for self-absorption correction	0.99	0.99	1.00	0.99	0.99

2) Performance of the five lamps at DC supplies voltage.

The average values of the measuring $Ø_L$, W_L, I_L, V_L and efficacy for the five lamps are represented in Table 2.

Table 2 Performance of each lamp type at fixed DC volt

Lamps (W)	V_L	$Ø_L$	W_L	I_L
25	90.4	125	25	0.21
40	109.5	417	40	0.38
75	109.0	915	75	0.71
100	105.6	1 262	100	0.91
200	101.1	2 583	200	1.78

3) Determination of σ mismatch correction factor

The mismatch correction factor has been measured five times for each lamp, accordingly the values of mismatch correction factor are illustrated in Table 3.

Table 3 σ for mismatch factor correction for five lamp types

Lamps (W)	25	40	75	100	200
σ for mismatch correction factor	0.978	0.979	0.979	0.989	0.988

4) The performance of each lamp type at a certain color temperature is shown in Table 4 according to the Krtil reports on photometric measurements[11].

Table 4 Performance of each lamp type at a color temperature

Lamps (W)	V_L	$Ø_L$	W_L	I_L
25	85.9	103	25	0.20
40	105.9	366	40	0.38
75	109.6	931	75	0.71
100	105.0	1 237	100	0.90
200	104.1	2 862	200	1.79

5) The values of flux $Ø$ are repeatable with standard deviation σ are represented in Table 5.

Table 5 Average value of σ of repeatability of luminous flux for five lamps

Lamps (W)	25	40	75	100	200
Average value of σ of repeatability of luminous flux	0.08	0.28	0.28	0.28	0.40

6) The results of calibration and conclusion

According to the experimental results work and attributed calibrations, the uncertainty budget for luminous flux calibration for the five lamps are illustrated in Tables 6—10. (k=2 means the confidence level is 95%).

Table 6 Uncertainty budget for luminous flux of (F5) lamp

Uncertainty factor (F5)	Type A %	Type B %
Calibration of luminous flux standard lamp		0.8
Aging of the working standard lamp		0.5
Self absorption correction	0.000 3	
Spectral mismatch correction	0.001 1	
Repeatability of test lamp	0.011 0	
Expand uncertainty of test lamp	±1.88	±1.88

Table 7 Uncertainty budget for luminous flux of (F9) lamp

Uncertainty factor (F9)	Type A	Type B
Calibration of luminous flux standard lamp		0.8
Aging of the working standard lamp		0.5
Self absorption correction	0.000 3	
Spectral mismatch correction	0.000 6	
Repeatability of test lamp	0.025 0	
Expand uncertainty of test lamp	±1.88	±1.88

Table 8 Uncertainty budget for luminous flux of (F20) lamp

Uncertainty factor (F20)	Type A %	Type B %
Calibration of luminous flux standard lamp		0.8
Aging of the working standard lamp		0.5
Self absorption correction	0.000 4	
Spectral mismatch correction	0.000 6	
Repeatability of test lamp	0.028 0	
Expand uncertainty of test lamp	±1.88	±1.88

Table 9 Uncertainty budget for luminous flux of (F22) lamp

Uncertainty factor (F22)	Type A %	Type B %
Calibration of luminous flux standard lamp		0.8
Aging of the working standard lamp		0.5
Self absorption correction	0.000 2	
Spectral mismatch correction	0.000 6	
Repeatability of test lamp	0.020 0	
Expand uncertainty of test lamp	±1.88	±1.88

Table 10 Uncertainty budget for luminous flux of (F29) lamp

Uncertainty factor (F29)	Type A %	Type B %
Calibration of luminous flux standard lamp		0.8
Aging of the working standard lamp		0.5
Self absorption correction	0.000 2	
Spectral mismatch correction	0.000 6	
Repeatability of test lamp	0.023 0	
Expand uncertainty of test lamp	±1.88	±1.88

6 Conclusion

A photometric method to ensure the drift in the recalibration values for NIS working standard lamps during last year is built up at the NIS. According to Table 2, the drift ranges from 0.3 % to 6.8 % depending on their wattages and color temperatures. Correction due to the spectral mismatch factors is calculated for each lamp and found to be from 0.978 when using the 2 351 K standard lamps to 0.989 when using the 2 788 K standard lamps. Also, the associated expanded uncertainty with the spectral mismatch correction factors is calculated to be 1.88 based on the correlated color temperature of the standard lamps. Table 4 reveals that there is no considerable change between the old and new color temperature.

With this new recalibration, NIS (Egypt) maintains the national scales for luminous flux in lumen and these five working standard lamps are very important for use in the routine calibration work.

1) The results of experimentally obtained values of luminous flux of five lamps at the calibration values of DC supply voltage are represented in Tables 5—9.

2) We have found that the uncertainties of lamps improvement become 1.5% instead of ±2.17%.

3) These lamps provide the realization of luminous flux scale in the photometry laboratory in NIS and also inspection organization and industrial laboratories.

4) There is no change in the performance of lamps at fixed color temperature of fixed voltage

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工作标准灯组的再标定

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摘　要： 对埃及国家标准化研究所使用的由欧思朗公司生产的标准工作灯进行了再标定，同时完成了相关的不确定性扩大的预算。用一个积分球、一个标准测光仪、五个由英国国家物理实验室标定的25－200 W的光通量标准灯组成的试验装置对埃及国家标准化研究所的五个工作标准灯进行了测量和再标定，使之保持国家级的测量水平。

关键词： 光通量；工作标准灯；标准测光仪；积分球

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