EFFECTS OF BAFFLE IN AN INTEGRATING SPHERE ON THE TOTAL LUMINOUS FLUX MEASUREMENT OF A LINEAR-SHAPE LAMP

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Abstract − The measured total luminous flux of a linear-shape lamp by using an integrating sphere can be deviated from accurate by the presence of a baffle in the sphere. For the lamp with co-axial alignment, the measured flux decreased when the baffle was longer. But with perpendicular alignment, the trend was opposite. When the baffle was further away from the detector, the measured flux decreased. These were due to the interplay of the non-uniform regions the baffle induced in the sphere.

Keywords: Integrating sphere, total luminous flux, linear-shape lamp, sphere uniformity, spatial correction factor.

1. INTRODUCTION

The integrating sphere substitution method is one of the convenient ways to realise the total luminous flux of a light source [1]. The method mainly comprises an integrating sphere, a standard light source with a known flux value, and a test light source, the flux of which is to be measured. The integrating sphere is a hollow sphere, the inner wall of which is coated with a highly reflective material. Once there is a light source inside, due to the high reflective spherical-shaped wall, multiple reflections occurs. This leads to the illuminance of the light source at every point on the sphere wall to be theoretically uniform. This uniform illuminance of the light source is detected by a photo-detector installed somewhere on the sphere inner wall. The photometer then measures the illuminance in a form of electrical signal. In order to measure the total luminous flux of the test light source, both the standard and test sources would be, one at a time, installed at the centre of the sphere. The electrical signal of each light source, detected by the photo-detector, is consequently obtained. As the total luminous flux of the standard source is know, such value for the test source could be calculated, hence the name substitution method.

An important component of an integrating sphere is a baffle, installed between the light source and the photo-detector. Its duty is to shield the direct light from the light source not to incident on the photo-detector, thus the photo-detector would receive only the light resulted from the multi-reflection. However, the existence of the baffle makes the sphere losses its uniformity, hence the inaccurately measured total luminous flux of the source. The inaccuracy in the measured value would be enhanced if the luminous intensity distributions of the standard and test sources become more different.

The test light source of linear shape such as a linear fluorescent lamp or a linear LED lamp is a good example of light source with a luminous intensity distribution greatly different from that of the standard source which is usually a spherical incandescent lamp. Moreover, the alignment of a linear-shape lamp in an integrating sphere can be varied. Due to these varieties, the baffle inside the integrating sphere may have different conditions. And thus the total luminous flux measurement of lamps with this shape by using the integrating sphere substitution method must be taken with care in order to reduce the inaccuracy.

This paper reports the study of the effects of the baffle in an integrating sphere on the total luminous flux measurement of a linear-shape lamp at two different lamp alignment configurations: coaxial and perpendicular. Two baffle conditions − size and position − have been mainly studied. The effects of such conditions on the total luminous flux have been studied through a correction factor called spatial correction factor and its relative uncertainty. The result could be used to adjust the baffle condition in order to optimise the accuracy of the measured total luminous flux.

2. EXPERIMENTAL

The integrating sphere used in this work is a LMT integrating sphere with the diameter of 2 m, where the lamp was to be installed at the sphere centre. The sphere inner wall was coated with LMT PHP80 paint with a reflectance of approximately 80%. The right hemisphere was movable for sphere access, while the left one was fixed firmly. At the centre on the left hemisphere wall was the photometer, in front of which was a baffle.

The effects of the size and position of such baffle on the total luminous flux of a linear-shape lamp were studied in three following categories:
(1) Effects of the baffle size on the total flux of a linear-shape lamp with a co-axial alignment (i.e. the lamp aligned towards the photo-detector, as shown in Fig. 1a)
(2) Effects of the baffle size on the total flux of a linear-shape lamp with a perpendicular alignment (i.e. the lamp aligned perpendicular to the line from the photo-detector, as shown in Fig. 1b)
(3) Effects of the baffle distance on the total flux of a linear-shape lamp with a perpendicular alignment.
In each specific condition, the experiment was started where the spatial response distribution function, *K*, of the
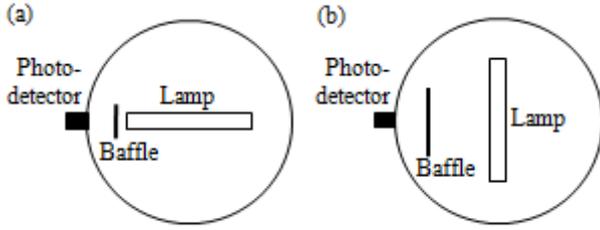
Fig. 1. (a) Coaxial and (b) perpendicular arrangement of a linear-shape lamp inside the integrating sphere.
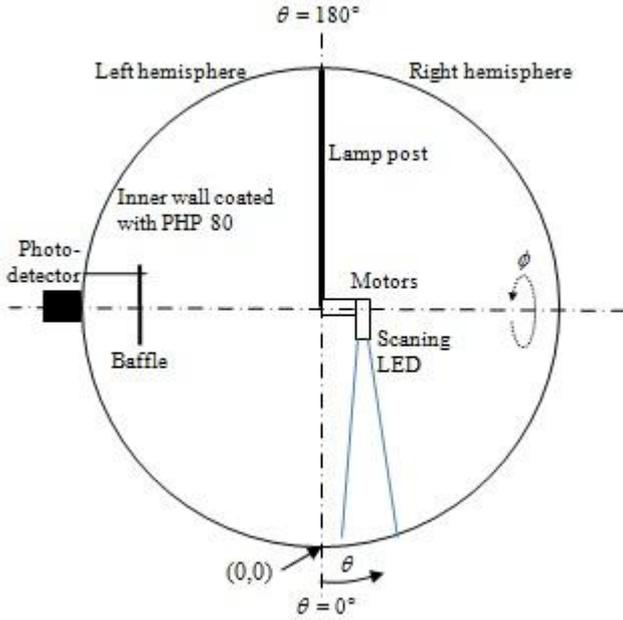

Fig. 2. Schematic diagram of the sphere with the scanning LED to obtain the spatial response distribution function, K, of a specific baffle condition.

sphere was determined. This parameter was obtained by rotating a scanning LED with an aperture diameter of 33 mm to sweep, at a 5-degree step, around the whole sphere inner wall as shown in Fig. 2. At each angular position (θ,ϕ) on the wall, the photo-signal detected by the photo-detector was collected.

Apart from obtaining K from the sphere, the luminous intensity distribution, I, of a standard spherical lamp and a linear-shape lamp were also acquired. This parameter was obtained by sweeping a mirror-type gonio-photometer at a 5-degree step around a lamp. In this study, five linear fluorescent lamps of different diameter, length, and colour correlated temperature (CCT) were selected as follows:

Table 1. Detail of lamps used in this study.

Lamp	Diameter (mm)	Length (mm)	CCT (K)
A	26	1175	~6120
B	26	1175	~2820
C	26	560	~6120
D	26	560	~3865
E	16	1130	~6120

K and I were then used to calculate the spatial correction factor, scf. This parameter is a factor identifying how different the measured total luminous flux value is from the accurate value when the luminous intensity distributions of the standard and test lamps are different. Such factor of the standard lamp, scf_{std}, and of the test lamp, scf_{test}, can be calculated as follows [2]:

$$scf_{std} = \frac{1}{\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} I_s^*(\theta,\phi)K^*(\theta,\phi)\sin\theta\, d\theta\, d\phi}, \qquad (1)$$

$$scf_{test} = \frac{1}{\int_{\phi=0}^{2\pi}\int_{\theta=0}^{\pi} I_t^*(\theta,\phi)K^*(\theta,\phi)\sin\theta\, d\theta\, d\phi}. \qquad (2)$$

Here, $I^*(\theta,\phi)$ is the normalised luminous intensity distribution of the lamp at the angular position (θ,ϕ) on the sphere inner wall, $K^*(\theta,\phi)$ the normalised spatial response distribution function of the sphere at the same (θ,ϕ) position. The subscriptions s and t denote that the value belongs to the standard and test lamps, respectively.

Once scf_{std} and scf_{test} have been obtained, the final scf of the measuring system can be calculated as the ratio of scf_{test} and scf_{std} as follows:

$$scf = \frac{scf_{test}}{scf_{std}}. \qquad (3)$$

Due to the normalised nature of both I^* and K^*, the values of all scf_{test}, scf_{std}, and scf technically fall around one. The value of scf of exactly one indicates that the measured total luminous flux is equal to the accurate value. If scf is less than one, the measured value is higher than the accurate value, and vice versa. However, as K can be affected by the scanning step and the scanning LED aperture [3], the exact value of scf calculated in this study may be able to deviate. Thus the attention was paid on only on its trend.

The uncertainty of scf was determined through a Monte-Carlo simulation; the factor was calculated for 10,000 times and its relative uncertainty was calculated under the rectangular distribution assumption with the coverage factor, k, of one.

3. RESULTS AND DISCUSSION

3.1 Typical spatial response distribution function

Fig. 3 shows a typical spatial response distribution function, K, of the sphere used in this experiment obtained with a presence of a circular baffle. The result was as expected where K was not uniform all over the sphere mainly due to the baffle. Two distinct characteristics can be observed: (1) the high-signal, circular region at the centre of the left hemisphere where the photo-detector and the baffle were located, and (2) the low-signal, circular region at the centre of the plain right hemisphere.

The high-signal characteristic at the left hemisphere, from our previous study [3], was due to the light incident at the sphere wall around the baffle, reflected to the back of the baffle, and again reflected from the back of the baffle to the photo-detector; hence the signal at that area was higher than that in the surroundings. For the low-signal characteristic at the right hemisphere, this was due to the shadow of the baffle seen by the photo-detector.
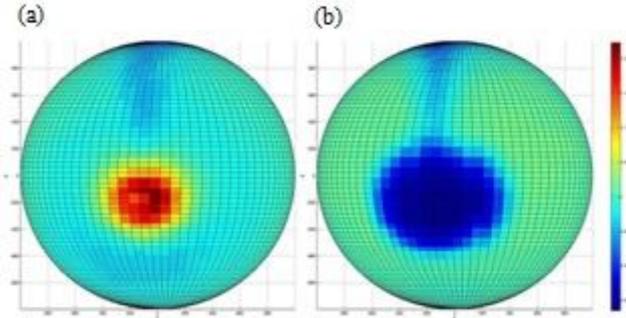
Fig. 3. A 3-Dimensional plot of typical K of (a) left (b) right hemispheres of an integrating sphere with a circular baffle.

3.2 Effects of baffle size on the total luminous flux of a linear-shape lamp with co-axial alignment

The effect of the baffle size on the total luminous flux of a linear lamp with co-axial alignment as shown in Fig. 1a was studied. The baffle shape was in a racetrack shape as shown in Fig. 4, with the width, w, fixed at 120 mm, and the length, l, varied from 120 mm to 520 mm. (i.e. when l equalled 120 mm, the baffle was in a circular shape.)

Fig. 5 shows the relations between the length, l, of the baffle and scf of the system and its corresponding relative uncertainty. The scf of all lamps exhibited a similar trend where the value of scf and its relative uncertainty increased increasingly with the length l of the baffle. The value of scf increased from 0.996 to 1.003 when l increased from 120 mm to 520 mm, respectively. This indicates that, for this co-axial arrangement, once the baffle became longer, the measured total luminous flux would decrease.

The reason of this trend, we believe, is due to the increase in size of the low-signal region opposite to the baffle. In the integrating sphere method, the total luminous flux of the test lamp, Φ_{test}, can be calculated from the ratio of the photo-signal of the test lamp, y_{test}, to that of the standard lamp, y_{std}, multiplied by the total luminous flux of the standard lamp, Φ_{std}, as shown in Equation (4) below:

$$\Phi_{test} = \frac{y_{test}}{y_{std}} \cdot \Phi_{std}. \tag{4}$$

Once the baffle was longer, the area of shadow, as shown in Fig. 3b, produced by the baffle became larger. When the lamp was in a spherical shape, the ratio of the extended shadow region compared to the original shadow region was small. However, for a linear-shaped lamp with a co-axial arrangement, this ratio was larger. This was because in the original shadow region, the light intensity was small as it is around the area a cap of the lamp illuminated. Due to these reasons, when the baffle was longer, y_{test} would decrease in a greater portion compared to y_{std}, resulting in a lower measured total luminous flux value.

The relative uncertainty of scf in this lamp alignment was also increased with the baffle length. However, such uncertainty was less than 0.08% which may be considered to be relatively small compared to other uncertainty components.
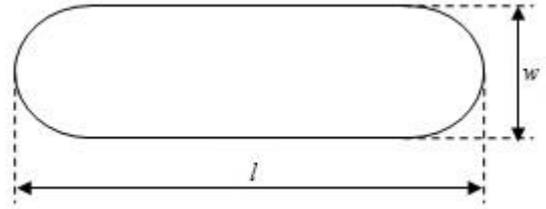

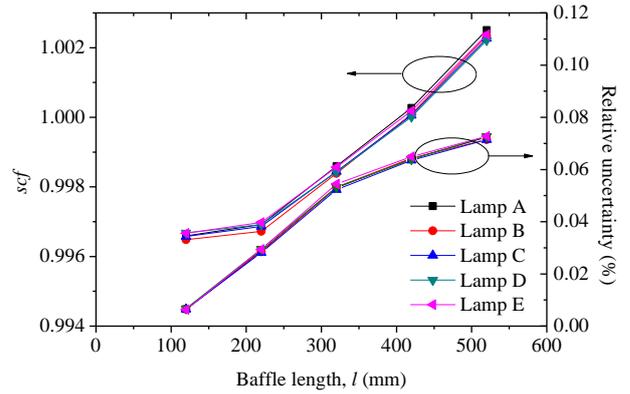Fig. 4. Sketch of the racetrack shape of baffle with width w and length l.

Fig. 5. Relations between the baffle length, l, and scf and its uncertainty of linear-shape lamps with co-axial alignment.

3.3 Effects of baffle size on the total luminous flux of a linear-shape lamp with perpendicular alignment

In this study, the lamp alignment was in a perpendicular configuration as shown in Fig. 1b, while the baffle shape was still racetrack and had the same sizes as those used in the previous section. This alignment is typical for a linear shape lamp with a racetrack baffle. The effects of the baffle length, l, on scf and its relative uncertainty were shown in Fig. 6.

Compared to the effect of baffle length on scf in the co-axial arrangement, in the perpendicular arrangement, such effect was reversed. In this alignment, scf decreased when the baffle length l increased. From l of 120 mm to 520 mm, scf decreased from 1.004 to 0.996. This indicated that, for this lamp alignment, if the baffle length was longer, the measured total luminous flux would be increasing.

The reason behind this trend may be mainly attributed to the increase in the height and area of the high-signal region behind the baffle. When the baffle became longer, some part of the baffle will be closer to the sphere wall (keeping that the position of the baffle was fixed). This resulted in a higher and larger high-signal region around the photo-detector. However, this effect was not the same for the standard and test lamps where the effect for the latter was more pronounced. This was because, for the perpendicular alignment, the illuminating position of the test lamp with a linear shape would be closer to the baffle than that of the standard spherical lamp. Thus, when the baffle was longer, y_{test} would increase in a greater portion compared to y_{std}. This, regarding Equation (4), would result in a higher measured total luminous flux value. The low-signal region
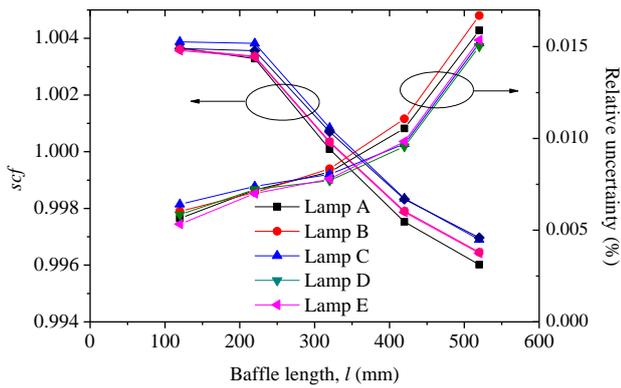
Fig. 6. Relations between the baffle length, *l*, and *scf* and its uncertainty of a linear shape lamp with perpendicular

also became larger, but the effect from the low-signal region was overshadowed by the increase in the height of the high-signal region.

The relative uncertainty of *scf* in this lamp alignment was opposite where it increased with baffle length. The uncertainty of *scf* from perpendicular alignment was several times lower than that from co-axial alignment obtained from the same baffle size. This indicated the better measurement performance of this alignment than that of the co-axial one.

3.3 Effects of baffle distance on the total luminous flux of a linear-shape lamp with perpendicular alignment

Two main non-uniformity characteristics which occur due to the appearance of the sphere are the high-signal region in the baffle-side hemisphere and the low-signal region in the opposite plain hemisphere as shown in Fig. 3a and 3b, respectively. Both affect *scf* differently and separately where the increase in height or area of the high-signal region would lead to the higher measured total luminous flux value, while the increase in the area of the low-signal region would lead oppositely. To confirm this, the effects of each characteristic need to be studied separately, while the other needs to be controlled.

In this section, the effect on the high-signal region on *scf* was studied where the size of the low-signal region was controlled to be approximately constant. This was done by moving the baffle at 5 different distances, *d*, from 58 mm to 250 mm, from the photo-detector. While the baffle was moving further away from the photo-detector, the length of the baffle, *l*, increased such that the low-signal region (the baffle shadow) at every baffle condition was of the same size. Fig. 7 shows the schematic diagram of the sphere and baffle when the baffle is at the furthest position from the photo-detector.

Fig. 8 shows the effect of baffle distance, *d*, on *scf* where the shadow size was controlled to be constant. The relation shows that, once the baffle was further away from the photo-detector, *scf* increased, indicating the decrease in the measured total luminous flux value. As the low-signal region (baffle shadow) was the same for baffle distance, the reason of this behaviour was because of the high-signal
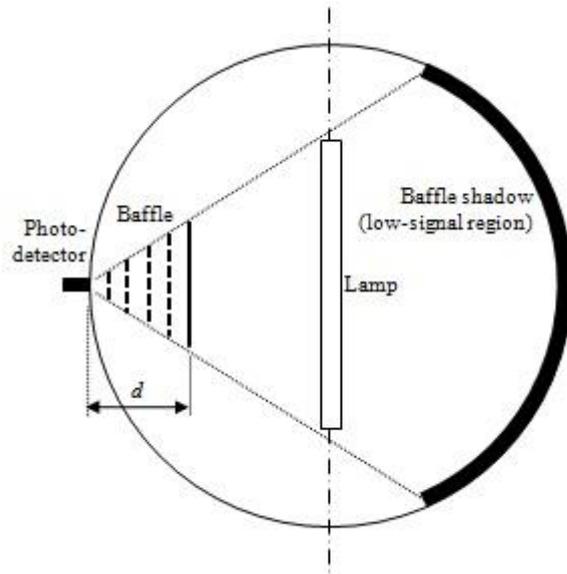

Fig. 7. Schematic diagram of the sphere and baffle when the latter was furthest away from the photo-detector. Other baffle positions are shown as dash lines. Here the lamp was in the perpendicular alignment.
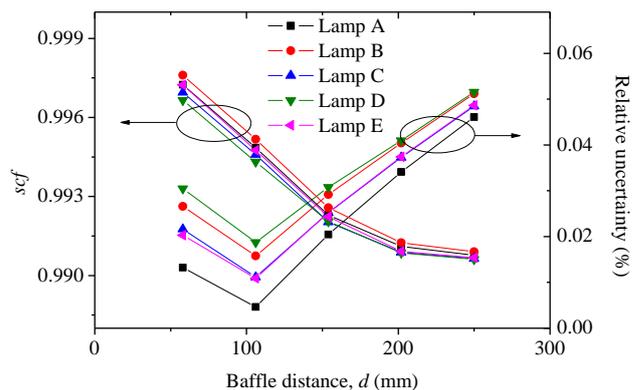

Fig. 8. Relations between the baffle distance, *d*, and *scf* and its uncertainty of a linear shape lamp with perpendicular alignment.

region generated around the photo-detector. When the baffle became further away from the detector, the signal at such area became lower, leading to the decreasing trend of the measured total luminous flux value.

4. CONCLUSIONS

Baffle is a crucial component in an integrating sphere used for measuring the total luminous flux of a linear shape light source. However, the presence of a baffle in front of the photo-detector in the integrating sphere created the non-uniformity inside the sphere where it produces a high-signal region behind the baffle and a low-signal region on the opposite side. This non-uniformity of the sphere response consequently leads to the deviation of the value of measured total luminous flux from accurate. By using the spatial

correction factor as a tool, the effects of a baffle on the trend of the measured total luminous flux value were studied.

Firstly, the effect of baffle size was studied. It was found that, for a linear lamp with coaxial alignment, when the baffle became longer, the measured flux value would decrease. This contradicted to the case of perpendicular alignment where the value of the measured flux increased when the baffle became larger. The difference in the measured flux value was around 0.2% for every 100 mm increase in length of the racetrack baffle in a 2-m integrating sphere. The reason behind these behaviours, we believe, was the interplay between the sizes of the high and low-signal regions.

The effect of the high-signal region was separately studied where the low-signal region was controlled to be constant. This was done by varying the baffle size and distance from the photo-detector. The result was that, once the baffle was further away from the photo-detector, the measured total luminous flux would decrease. This was due to the decrease in the height of the high-signal region when the baffle was further away from the photo-detector.

The results from this study can be useful for a detailed study of the sphere uniformity used to measure a total luminous flux of a test lamp with a different luminous intensity distribution from that of a standard lamp. As the presence of a baffle can affect the accuracy of the measured total luminous flux, its conditions including size and distance need to be carefully designed to provide the measured flux as accurately as possible.

REFERENCES

[1]   C. DeCusatis, *Handbook of Applied Photometry*, Springer, New York, pp. 82-85, 1997.

[2]   Y. Ohno and R. O. Daubach, "Integrating sphere simulation on spatial nonuniformity errors in luminous flux measurement", *J. Of Illuminating Engineering Society*, vol. 30(1), pp. 105-115, January 2001.

[3]   K. Wasapinyokul, R. Leecharoen, S. Chanyawadee, et al. "Effects of integrating sphere conditions on the spatial response distribution function in the total luminous flux measurement", *XX IMEKO World Congress*, Busan, Republic of Korea, September 2012.