"The design of a compact photometer for tubular fluorescent lamps"

S.V. Marais, C.R.Durrheim, M.J.Alport and T.B. Doyle.

ABSTRACT:

The accurate measurement of total luminous flux from long tubular fluorescent lamps is usually achieved by using a large diameter integrating sphere. A compact, high performance alternative is realized by integrating the light output over the entire length of the fluorescent lamp.

THE INTEGRATING SPHERE

The integrating or Ulbricht sphere is commonly used to measure total luminous flux from a source. The theory of an integrating sphere assumes an empty sphere whose inner surface is perfectly diffusing and of uniform non-selective reflectance. Every point on the inner surface then reflects to every other point, and the illumination at any point is therefore made up of two components; flux coming directly from the source and that reflected from other parts of the sphere wall. Consider a sphere of radius r which is great compared with the dimensions of the light source L at its centre (Figure 1). A point P on the inner surface of the sphere , shielded from direct light from the source by a small screen Q, receives light reflected from the whole of the remainder of the surface. The illuminance δE at P produced by an element δS of the surface at a distance d is given by:

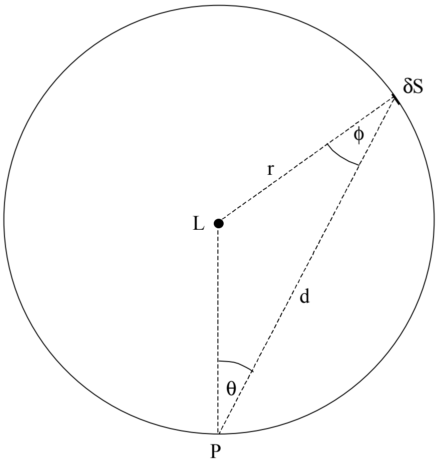

Figure 1: The integrating sphere

$$\delta E = \frac{L\delta S \cos\theta \cos\varphi}{d^2}.$$

From the geometry of the sphere $\theta = \varphi$ and $d = 2r\cos\theta$ so that

$$\partial E = \frac{L\partial S}{4r^2}$$

and

$$E = \frac{1}{4r^2}\int L dS$$

the integral being taken over the whole surface of the sphere, with the obstruction due to the screen being ignored. The above equation shows that illuminance at a point on the sphere due to reflected light from the rest of the sphere is the same at all points on the sphere, regardless of how L varies over its surface[1,2,3]. It follows that the light source need not be positioned exactly in the centre of the sphere to achieve good results[4]. A sensor positioned on the sphere surface, shielded from direct light from the source, thus collects flux emitted from the source in every direction, *i.e.*, 4π steradians. This arrangement works well with small spherical sources and, if various correction factors are applied, can be used for absolute measurements[3].

ERRORS WITH EXTENDED LIGHT SOURCES

The use of an integrating sphere with long tubular fluorescent lamps can result in errors due to the increased screen size necessary to shield the sensor from direct light. The shield then removes dissimilar contributions of flux along the lamp length from reaching the sphere wall thereby departing from basic integrating sphere theory. For these reasons the dimensions of the integrating sphere should be at least six times the overall length of the lamp[1]. Even when strict substitution is applied the diameter of the sphere should be at least 1.5 times the length of the lamp[1,3]. The minimum sphere diameter required to measure a 1.5m long lamp would be 2.25m for direct substitution and 9m for absolute measurements. Both requirements would result in a device of considerable proportions which may not be comfortably accommodated. Direct substitution is easily realised if reference light sources are available but rapid developments in lamp design has resulted in an ever growing number of different lamp lengths and diameters.

A CYLINDRICAL INTEGRATING PHOTOMETER

An alternative to accurately measuring the total luminous flux of a tubular fluorescent lamp by using a very large integrating sphere is to sum the contributions of all the radiating surfaces of the lamp by using multiple sensors, arranged longitudinally, inside a cylindrical integrating chamber. The sensors then receive contributions of reflected flux along the entire length of the lamp. The output from these sensors is summed to yield a single reading of total luminous flux.

The tubular integrating photometer (Figure 2) has 70 screened sensors, covered by an opal plastic diffuser, positioned along the entire longitudinal axis. The lamp is confined in a clear acrylic tube and kept cool by forced ventilation. A screen is positioned one third of the distance from the lamp to the sensor and is large enough to shield direct flux reaching the sensors. The inside of the chamber, including the chamber end plates, and the screen is coated with a white diffusing paint. Blackened end caps prevent external light from entering the photometer. The photometer cylinder is 2m long with a diameter of 0.63m.

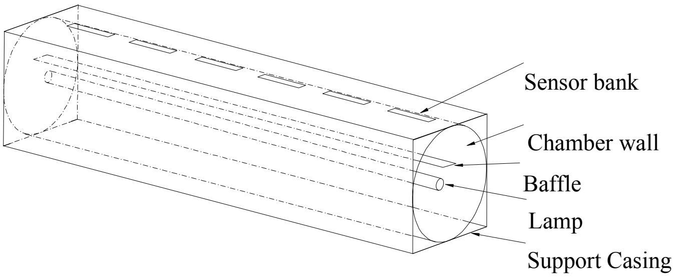

Figure 2: A tubular integrating photometer

The paint used inside the photometer must exhibit Lambertian or cosine diffuse reflection where incident flux is scattered equally in all directions. The luminous exitance (lm/m^2) should decrease by the cosine of the angle from the normal; this effect being entirely due to the decreased projected area of the source. A white matt acrylic paint with a high reflectance of 95% is used. Figure 3 shows the apparatus used to determine the quality of the diffuse reflection of the paint, the sensitivity law for the photoconductive cell and to characterise the diffuse transmittance of the opal plastic.

The measurement of the paint luminous exitance (lm/m^2) at various angles from the normal was initially attempted but reflection other objects severely compromised results. Measurement of surface brightness (lm/m^2sr) with angle yielded more consistent results. A large painted surface was uniformly illuminated by an incandescent light along the normal axis. A photocell and a screen with a small aperture were mounted on the movable arm. The aperture ensured that the projected area viewed by the photocell remained constant at all angles. The measurement of surface brightness or luminance (lm/m^2sr) yielded a constant value, within 10%, through angles up to 75^o from the normal; the paint therefore exhibits good Lambertian reflection properties. Measurement of angles above 75^o was not possible due to apparatus limitations.

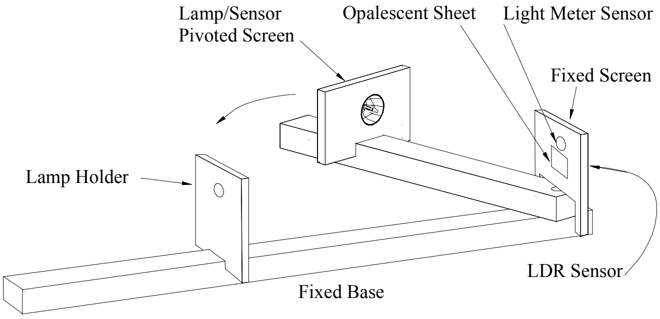

Figure 3 Test apparatus

Photoconductive cells manufactured from cadmium sulphide with a peak sensitivity of 540nm and minimum gamma (γ) characteristics of 0.6 are used for the sensors. The photoconductive cell spectral response closely matches the photopic or *V(λ)* response of the human eye. The gamma characteristic is given as the tangent of a straight line passing through two points of the sensitivity curve[5]. These two points are usually the resistance measured at 10lx (R_{10}) and 100lx (R_{100}). The gamma characteristic is therefore:

$$\gamma = \log\left(\frac{R_{10}}{R_{100}}\right)$$

As the gamma characteristics vary from cell to cell it was important to characterise the sensitivity of each cell.

The photocell in an integrating chamber must be cosine corrected to ensure that its sensitivity remains constant at all incident flux vectors. Excellent Lambertian diffusion is obtained by using a solid opalescent medium although absorption is high[1,3,6]. Tests on solid opal plastic were performed using the apparatus shown Figure 3. The photoconductive cell, located behind the opal sheet, was illuminated by a parallel beam light source mounted on the movable arm. A cosine corrected luxmeter was positioned on axis just above the cell. Since flux density was being measured, it was expected that the output from the luxmeter would exhibit a cosine angular response. Figure 4 shows the measured, calibrated cell angular response behind the opal plastic, the luxmeter angular response and the cosine function. It is clear that the opal plastic exhibits good Lambertian transmittance.

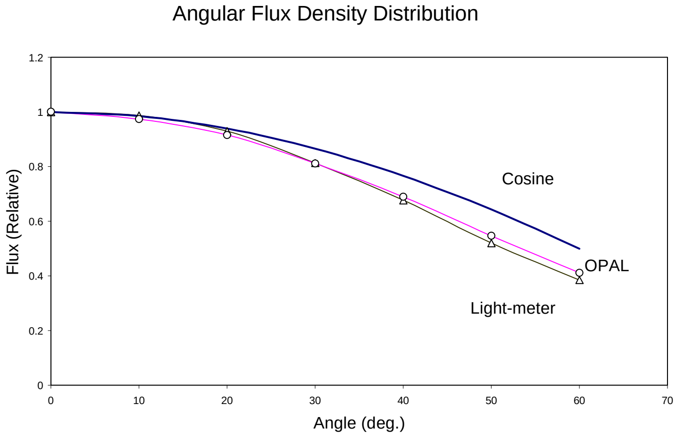

Figure 4 Measured angular response of opal plastic

In order to establish the contributions of flux from the entire extended source to each sensor a point light source was dragged through the acrylic tube (with the screen in place) whilst noting the output of a single sensor positioned centrally. As can be seen in Figure 5 the output initially drops by 0.3% per centimetre thereby justifying the use of multiple sensors positioned at 2.5 cm intervals.

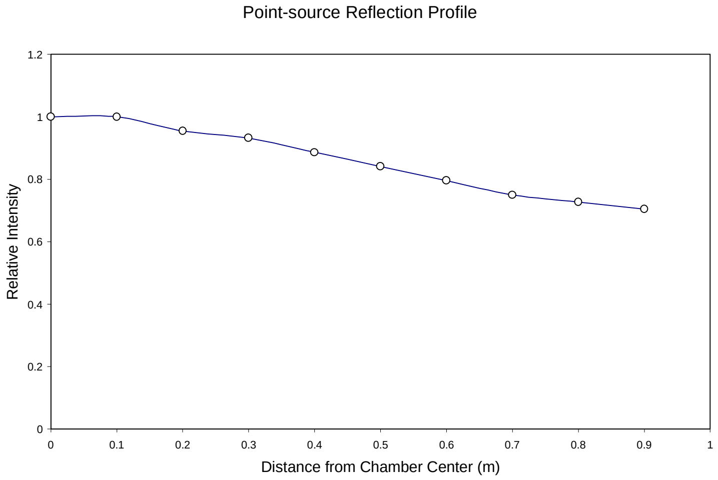

Figure 5 Output of centre sensor

No integrating sphere was available for comparative studies but initial tests revealed that the cylindrical photometer is well suited for substitution measurements at this stage. Further development will involve the measurement of paint selectivity, cell spectral response and methods to facilitate comparative measurements of lamps of dissimilar length.

References

1. S.T. Henderson and A.M. Marsden, “Lamps and Lighting” Edward Arnold.
2. R.W. Boyd, “Radiometry and the detection of optical radiation”, John Wiley.
3. Illuminating Engineering Society of North America, “IES Lighting Handbook” 1984.

4. R. Grum and R.J. Becherer, "Optical radiation measurements", Academic Press.
5. J.A. Allocca and A. Stuart, "Transducers:Theory and Applications", Reston Publishing.
6. T.B. Brill, "Light", Plenum Press.

The authors can be contacted at:
Applied Physics Group
School of Pure and Applied Physics,
University of Natal,
Durban,
South Africa
Fax: (031) 261 6550
e-mail: Maraiss4@nu.ac.za

The Authors:
Stirling Marais and Craig Durrheim are currently studying for a PhD (Phys) and MSc (Phys) respectively whilst setting up an industrial lighting testing facility at the University of Natal. Prof. Michael J. Alport is the head of the Applied Physics Group**.** Prof. Terry B. Doyle is the head of the School of Pure and Applied Physics.