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Integrating Sphere Measurement Part I: Basics

This Technical Note is Part I in a three part series examining the proper maintenance and use of integrating sphere light measurement systems. This first Note is an overview of basic sphere theory, operation, and equipment. Parts II & III will focus on specific flux measurement procedures and integrating sphere equipment details.

This article builds on previous Technical Notes available at www.lightingglobal.org

Introduction

An integrating sphere is often used to measure the light output of pico-powered lighting products. Sphere measurements are able to capture the key light output parameters of total luminous flux (in lumens) and the spectral qualities (color rendering index (CRI) and correlated color temperature (CCT)) of the light source. In order to produce accurate, repeatable results, an integrating sphere must be properly calibrated and the equipment must be correctly configured to avoid testing errors. Technicians using the equipment should be familiar with basic integrating sphere theory, proper equipment set-up procedures, and good maintenance practices. Sphere equipment is expensive and mistakes can be costly in terms of both equipment downtime and the costs required to repair or replace damaged equipment. This Technical Note series will cover the basic use and maintenance of an integrating sphere system to measure the luminous flux output of pico-powered lighting products.

Integrating Sphere Theory

An integrating sphere is a hollow sphere with a white, highly reflective, diffuse coating on the inside. When a lighting product, which we will refer to as the device-under-test (DUT), is placed inside the sphere and turned on, the luminous flux illuminates the inside surface through a series of multiple diffuse reflections (Figure 1). It can be shown mathematically that for a perfect sphere with a 100% reflective, perfectly diffuse (Lambertian) coating, every point on this surface receives or reflects the same amount of light; the light is spread uniformly over the entire surface. This also means that a measurement with an illuminance meter or spectroradiometer will be the same no matter where on the surface the measurement is taken.

For real systems, the reflectance will not be 100% and there will be ports, baffles, and mounting posts that influence the response of the sphere to different light sources. The sphere ***throughput*** is defined as the ratio of the collected flux at the detector to the total flux from the light source and is one measure of the efficiency of the sphere system. Anything placed inside the sphere during a test (wires, connectors, the DUT itself) will alter the sphere throughput and must be accounted for (corrected) in the final measurement.

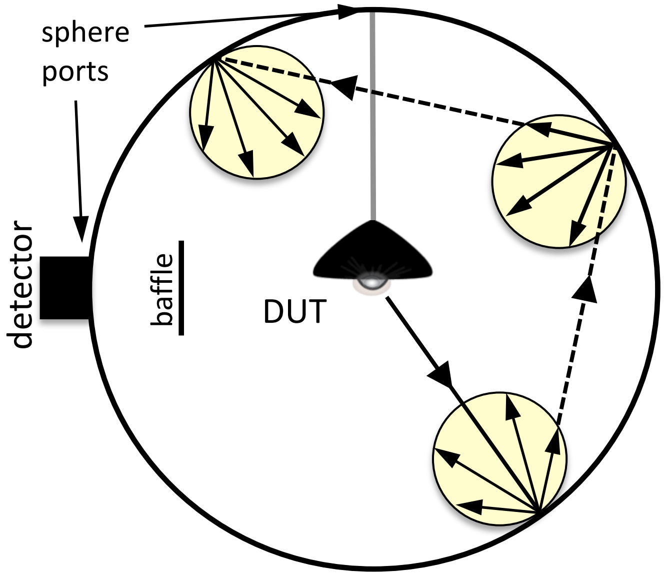

Figure 1. Multiple diffuse reflections inside an integrating sphere spread the light uniformly over the entire surface. In a (theoretical) perfect system the radiance from any point on the sphere's surface is the same regardless of the distribution of the light source.

Lamp substitution

An integrating sphere makes relative measurements of luminous flux by comparing the output of a test lamp (i.e. the DUT) to the output of a **standard lamp**. This is called lamp substitution. In practice, a standard lamp of known flux output is placed in the sphere and a measurement is taken. A test lamp is then 'substituted' into the sphere and another measurement taken. The response of the detector during these two tests is then used to calculate the flux output of the test lamp.

Calibration

The first test with the standard lamp establishes the sphere/detector response to a known flux value. The standard lamp itself is created and tested by another lab and should ultimately be traceable to an official (national) test standard. This **calibration process** is essential to the proper functioning of an integrating sphere system, and great care must be taken to ensure that the standard lamp and sphere equipment are properly used and maintained. Regular, frequent calibration cycles are a necessary part of normal sphere operation.

Auxiliary correction (self-absorption)

When a test lamp is placed in the sphere, the throughput is altered from **self-absorption** of the sphere reflections by the test lamp housing and lens. For pico-powered lighting appliances the throughput is typically lowered because the appliance housing absorbs more light than the standard lamp holder, but this is not always the case. In order to eliminate this self-absorption error, a correction is made using an **auxiliary lamp** (this is sometimes referred to as an 'AUX correction').

Integrating Sphere Equipment

Sphere coatings

Highly reflective sphere coatings in the 95-98% range are typical for systems used to test LED light sources. Higher reflectance values help to ensure good spatial integration of the flux from the DUT. Spatial integration (spreading the light uniformly over the sphere wall) is particularly important for LEDs, which often have asymmetrical and sometimes highly focused distributions.

A very high reflectance helps to achieve good sphere throughput and brings the sphere performance closer to the ideal case outlined by basic integrating sphere theory. However, high reflectance paints are also very sensitive to small variations in the sphere environment and equipment. This can lead to significant testing errors, so regular maintenance and accurate calibration are extremely important. Many sphere paints are delicate and must not be touched. Small amounts of airborne dust, not readily visible to the operator, will settle on the bottom of the sphere and cause testing errors. Clean, oil-free compressed air should be used to periodically blow out the inside surface.

Sphere size

The diameter of the integrating sphere determines the practical limit of the size of the luminaire that can be tested. It is generally recommended that the total surface area of the DUT be less than 2% of the surface area of the sphere wall and that the length of a linear DUT should not exceed 2/3 the diameter of the sphere. Lighting Global has found that a 1-meter sphere diameter is adequate for testing most pico-powered lighting products.

Detectors

The light receiver at the detector port is often a diffuse, semi-transparent collector that 'views' the interior surface of the sphere through a port in the sphere wall. The receiver should be coplanar with the sphere wall and exhibit a cosine response to the incoming light. Two types of detectors are commonly used with integrating spheres when measuring LED luminaires:

-Spectroradiometers

A spectroradiometer (often referred to as a spectrometer) measures radiometric flux in discrete wavelengths and is capable of capturing the spectral power distribution (SPD) of a light source. A fiber optic cable connects a light receiver mounted on the sphere wall (at a port) to the spectrometer, which processes the incoming signal by sending the flux through a diffraction grating and analyzing the individual wavelengths with a charge-coupled device (CCD) detector array. The raw data output of the spectrometer is in counts per wavelength, where the counts correspond to the number of photons received by the CCD array at a particular wavelength. This represents the radiometric power (radiation energy per wavelength) of the light source. Software is then used to make the V(λ) correction for this radiation, and the output can then be display in photometric terms. V(λ) is the luminosity function and describes the spectral sensitivity of human vision. This is used to convert radiometric (energy) values to photometric (human vision) values.

-Photometers

Photometer detectors were commonly used for light measurement in integrating spheres before the advent of white LED light sources. The explosive growth of LED lighting technologies and advances in low-cost spectroradiometers have encouraged a transition away from photometer detectors and towards spectroradiometers. The color measurement capabilities of spectroradiometers are very well suited to the analysis of LED sources, though photometer detectors are still widely used and completely appropriate for this type of measurement.

A photometer head is placed directly on the sphere wall through a port. The detector element is similar to those found in illuminance meters, and may or may not include color measurement capabilities. The diffuse filter on the detector is responsible for the V(λ) photopic correction and the output will be in photometric terms. The V(λ) correction accuracy for the filter is critical in avoiding errors, particularly in the blue portion of the visible spectrum (430-470 nm) where there is often a spike in the LED output and the filter may exhibit a higher degree of inaccuracy.

Baffles

Baffles are used to prevent direct viewing of the DUT light source by the detector. Missing a baffle would lead to incorrect irradiance readings at the detector's receiver head because the radiance of the sphere wall and the direct radiant component of the DUT would combine to form an elevated reading. The baffle should be just large enough to completely block light from the DUT to the detector. Some sphere systems have different baffles that can be switched out for use with different DUTs. Detector baffles are typically placed by the sphere manufacturer and should be 2/3 to 1/2 the distance between the DUT and detector (closer to the detector).

Lamp standards and auxiliary lamps

Quartz tungsten halogen (QTH) lamps are typically used as standards for calibrating an integrating sphere. The flux output of a QTH lamp is smooth and continuous through the visible spectrum (380 -780 nm), and the output of a properly seasoned lamp is stable and repeatable for an adequate period of the lamp's lifetime. QTH lamps used for lamp standards in integrating spheres can range in power from 5 to 1000 watts. Most sphere systems used with pico-powered lighting products use QTH lamps from 35 to 75 watts with a correlated color temperature (CCT) at or near 2856 K. The light output of a lamp standard should be high enough to provide a strong signal to the sphere detector. Larger spheres will therefore use higher power lamp standards.

QTH standards are delicate and expensive, and thus should be treated with a high degree of care. The lamps are stored in padded containers and only handled with gloves to avoid oil deposits from fingers (lamps can be cleaned with alcohol if contamination is suspected). When powering a QTH lamp standard, the current should ALWAYS be increased and decreased gradually to avoid thermal shocks to the QTH's filament. Lamp standards should be purchased in sets of 3 when possible, as this allows the lamps to be checked against each other at the lab to monitor lamp stability and identify drift of any single lamp.

Auxiliary (AUX) lamps are also typically QTH, but these do not need to be seasoned and calibrated as with standard lamps. An AUX lamp is used only to make relative measurements and so the absolute value of the lamp output is irrelevant. The lamp output does need to be stable, however, and so proper management is still necessary. An LED source can also be used as an AUX lamp provided the output is high enough, stable, and the lamp is allowed to reach thermal equilibrium during use. The advantage to using an LED AUX lamp for LED products is that the AUX lamp output and the DUT output will be spectrally similar, and so the self-absorption measured by the AUX lamp will reflect the true self-absorption present in the sphere during the DUT test. The light output of the AUX lamp should be high enough to provide a strong signal to the detector. QTH lamps are typically 30-100 watts.

Lamp power supplies

Power supplies and electrical equipment used to power calibration lamps, auxiliary lamps, and DUTs are key components to an integrating sphere system. The accuracy of measurements depends on the calibration accuracy of the equipment, and this, in turn, is a function of correctly delivering power to the lamps and DUTs. Many manufacturers provide power supplies configured to properly ramp and run the lamp standards that they sell, although it is possible for a laboratory to use a single power supply for all of its electrical supply needs.

Testing standards and references

Several testing standards exist that outline proper test procedures for luminous flux measurements (Figure 2). Some were written before the advent of LED lighting technology, while others deal specifically with LEDs. All can provide guidance on test set-ups and practices. Reference materials are also widely available and can be very helpful to technicians who are new to luminous flux measurements or are considering new equipment purchases or laboratory improvements.

Integrating Sphere Technical References

Test Procedures

CIE 84-1989 The Measurement of Luminous Flux

CIE 127-2007 Measurement of LEDs

IESNA LM-45-00 Approved Method for Electrical and Photometric Measurements of General Service Incandescent Filament Lamps

IESNA LM-78-07 Approved Method for Total Luminous Flux Measurement of Lamps Using an Integrating Sphere Photometer

IESNA LM-79-08 Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products

Figure 2. Technical references for sphere photometry