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**DETECTOR BASED PHOTOMETRIC CALIBRATION OF
GONIOPHOTOMETERS**

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DETECTOR BASED PHOTOMETRIC CALIBRATION OF GONIOPHOTOMETERS

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Abstract

For the photometric characterization of a luminaire the goniophotometer is a fundamental instrument. From goniophotometric investigation the total luminous flux of the device under test (DUT) and the detailed luminous intensity distribution information can be gained. Usually one calibrates a goniophotometer by a standard total luminous flux reference source. By practice, one needs at least a set of three total luminous flux calibration sources which can be costly to maintain. An alternative way to calibrate goniophotometer systems was developed which can be applied to several types of goniophotometer systems including those which have additional optical elements (like mirrors). The detector system in the developed method can be a photometer or a spectroradiometer.

Keywords: Photometry, Goniophotometry, Calibration, Luminous Intensity

1 Introduction

Goniophotometry is one of the most complex photometry measurement procedure which can provide detailed information about the angular distribution of some photometric quantity (like the luminous intensity) of the light emitted by the device under test (DUT) which is not necessarily a luminaire. The measurement method is several decades old and was already used with traditional light sources. The principle of the measurement method basically didn't change but the instrumentation (including the data acquisition methods) and the technology of the mostly applied sources did change significantly.

Until now basically the following three CIE documents (CIE 1987, CIE 1989, CIE 1996) are dealing with the theory, the usage, the application methods and the calibration of goniophotometers:

- CIE 070-1987, The Measurement of Absolute Luminous Intensity Distributions,
- CIE 084-1989, The Measurement of Luminous Flux,
- CIE 121-1996, The Photometry and Goniophotometry of Luminaires.

The above documents discussing goniophotometry with slightly different aims, one is targeting the luminous intensity distribution (LID), while the others are focusing on luminous flux measurement. Recently the importance of absolute photometry has grown since luminaires with replaceable sources are less and less present.

As we can see the above documents are several decades old. The facts that the instrumentation has changed and that the properties of the newest light source technologies should also be taken into account a new updated document is needed. Using the essence of the above documents and the practical experiences of the experts working at professional and industrial laboratories and also at national metrology institutes CIE TC 2-78 is working on a new document to have all the recent and relevant information concerning goniophotometry in one single document.

In this paper a detector based photometric calibration method will be introduced which can be applied to goniophotometer types which are using illuminance meters. We won't discuss photometric calibration questions of luminance camera based goniophotometers or near field goniophotometers.

2 Goniophotometer types

The goniophotometer definitions in the available CIE documents developed further as the application area of goniophotometric measurements became wider and luminaires were not the only subjects of goniophotometric characterization. The following list shows the different definitions of goniophotometers in the well-known CIE documents:

- CIE 70-1987 Photometer for the measurement of the angular dependence of a photometric quantity.
- CIE 84-1989 Photometer for measuring the directional light distribution characteristics of sources, luminaires, media and surfaces.
- CIE 121-1996 Photometer for measuring the directional light distribution characteristics of sources, luminaires, media or surfaces.

Without describing the different goniophotometer types in all detail the most common principles of goniophotometer arrangements are introduced.

2.1 DUT is turned around two axes

This version of goniophotometer arrangement turns the DUT around two axes which are mutually perpendicular, in most cases around the DUTs horizontal and around the DUTs vertical axis. By using this arrangement the operation position will change continuously during the measurement, therefore this method is not suitable for sources which are sensitive to operation position change. In this arrangement the photometer is fixed at a sufficient distance.

2.2 DUT is turned only around its vertical axis

If a device is only rotated around its vertical axis the effect on the light output of the source is usually negligible. The movement in the other dimension is fulfilled by using a mirror and/or moving photometer and this second direction is perpendicular to the vertical axis.

2.3 DUT position is fixed

In this goniophotometer arrangement the DUT does not move et al and the photometer moves around it. A real or virtual photometer movement can be realized for example by applying a mirror or mirrors or by using robotic arms.

All the above goniophotometer arrangements are available in various dimensions from table top device up to a size of several meters depending on the device size intended to measure. In this paper the photometric calibration of the first two types (chapters 2.1 and 2.2) is discussed.

3 Calibration methods of goniophotometers

A goniophotometer is a complex electromechanical device which needs to be calibrated from various aspects to ensure a valid and traceable photometric result. Those aspects are among others the following: mechanical arrangement and angle measurement, questions of stray light, relative spectral responsivity, limiting photometric distance and the most important, the photometric standard. This paper is discussing the photometric calibration methods which are introduced in the following chapter.

3.1 Traditional calibration methods

In the already mentioned CIE documents the photometric calibration of goniophotometers is discussed slightly differently. The common in all three documents is the usage of a luminous intensity standard lamp. The problem with this calibration method is that a luminous intensity standard lamp has its fixed burning position which can restrict the angles where the calibration can be performed. Another method is to use a luminous flux standard lamp which has a calibrated total luminous flux value with its own uncertainty contribution. Total luminous flux standard lamps are typically still incandescent lamps with 4 Pi radiation pattern which can be a problem if a goniophotometer with a dead angle bigger than the dead angle of the source or even worse if the burning position of the luminous flux standard lamp was selected wrongly at the time of calibration. All the documents are mentioning the method where calibrated

photometers, or illuminance meters are in use, but not all of the documents is this method accepted as the photometric calibration. For example the CIE 84-1989 document recommends it to use an illuminance meter to test the calibration.

- CIE 70-1987, Chapter 14
 - calibration with luminous intensity standard lamp used with the burning position used at the time of calibration, or
 - a calibrated illuminance meter.
- CIE 84-1989, Chapter 5.11.2
 - testing or calibration by luminous flux standard lamp,
 - testing or calibration by luminous intensity standard lamp,
 - testing by calibrated illuminance meter.
- CIE 121-1996, Chapter 6.1
 - calibrated luminous intensity standard lamp, or
 - by using a previously calibrated photometer head to measure illuminance and converting to intensity using the photometric distance law.
 - Note: Absolute photometric measurements on luminaires are often unnecessary.

Even the most recent CIE document is more than 20 years old and since then new lamp technologies have been developed which show much greater variability in performance and optical solutions therefore absolute photometry got much more important nowadays.

To maintain a set of luminous intensity or luminous flux calibration lamps can be costly and the ageing of the incandescent lamps needs also special attention. Much robust calibration methods are the detector based solutions where a source is still needed to produce the light for the calibration but this source does not need to be calibrated only the requirement, that its light output should be stable needs to be fulfilled.

3.2 Detector based calibration methods

As we have seen the above CIE documents do mention detector based methods but only as a supplementary method. The authors think that a detector based calibration method is much easier to maintain compared to the source based methods and has much more benefits. Depending on the photometers scale point calibration they can be used for luminous intensities covering a much greater range by using simply a stable source with a smaller electrical power. As it is discussed in the CIE documents the luminous intensity in a specific direction can be derived by using the photometric distance law if the distance between the photometer and the source is known. For goniophotometer types where the DUT is turned around multiple axes the detector based photometric calibration is well known but for the types of goniophotometers where the photometer moves with other optical elements like mirrors the application of this method is not that simple. In the following the results of the detector based photometric calibration of two goniophotometers will be introduced. One is a luminaire turning goniophotometer with 5,0 m photometric distance, while the other one is a double mirror goniophotometer with 8,5 m photometric distance (Munoz-Martínez et al 2006).

4 Results

Figure 1 shows the schematic drawing of the luminaire turning goniophotometer. The luminaire is mounted on the construction shown on the left side and the photometer is mounted on the right side. For this type of goniophotometer the detector based photometric calibration is quite straightforward since the photometer in this case is simply a good quality $V(\lambda)$ -matched Silicon detector. The traceability is realized by the calibration certificate of the photometer head. By knowing the distance between the photometric centre of the

goniophotometer and the active layer of the photometer the luminous intensity at any measured angle can be calculated based on the well-known photometric distance law (Eq 1).

$$I_v = E_v \cdot d^2 \quad (1)$$

where

I_v is the luminous intensity;
 E_v is the illuminance;
 d is the distance.

Figure 1 – Schematic drawing of the luminaire turning goniophotometer

In case of the double mirror goniophotometer (see Figure 2) the photometric calibration needs a further step since there are two mirrors – a moving and a fixed one – in the optical path. The basic idea of the detector based photometric calibration of this type of goniophotometer is that a sufficiently small source (Fig. 3-a and Fig. 3-b) can be viewed by a calibrated photometer without having the mirrors in the optical path. This can be realized if a photometer is placed close the detector port (see marking *D* in Fig. 2. and Fig. 3-c) but centred on the vertical axis of the goniophotometer and aimed directly to the light source at point *H*. If this light source is sufficiently small then the calibrated photometer from point *D* then the luminous intensity can be derived if the distance is measured. If the luminous intensity is known of this – stabilized – source then it can be measured in the original arrangement by using both of the mirrors. Those two measurement runs differ only by the double mirror path therefore the ratio of the two runs will realize the traceable luminous intensity calibration of the goniophotometer system. The result is shown by Fig 4 where the derived luminous intensity by the calibrated photometer and the luminous intensity of the same light source is measured after the photometric calibration.

If a calibrated spectroradiometer is used at the position of the calibrated photometer then with the same method the spectral transmission of the goniophotometer system can also be derived.

Figure 2 – Schematic drawing of the double mirror goniophotometer (Munoz-Martínez et al 2006)

a)

b)

c)

Figure 3 – Light source placed to the photometric centre a), b) and the calibrated photometer below the source c)

Figure 4 – Luminous intensity values measured by the calibrated photometer and the goniophotometer after calibration of one C-slice

5 Conclusions

In the paper detailed description of both methods were presented which will show also the practical aspects of this new method applied on different types of goniophotometer systems. This method can be taken as an alternative method of using standard total luminous flux light sources. By replacing standard lamp based calibration, uncertainty is decreasing as parts of the uncertainty budget concerning transfer uncertainty, lamp stability, lamp ageing and power supply accurateness can be substituted by only one component of detector transfer uncertainty.

By using a standard photometer or calibrated spectroradiometer as the calibrating detector and a stabilized light source a detector based luminous intensity calibration can be realized on any goniophotometer system including those which have additional optical elements (like mirrors) between the measured light source and the photometer. In the latter case also the spectral transmission of the system can be characterized.

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