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TECHNICAL NOTE

Determination of the Optical Beam Axis, Centre Beam Intensity, and Beam Angle of Directional Light Sources

CIE TN 010:2019

This Technical Note has been prepared by CIE Technical Committee 2-78 of Division 2 “Physical Measurement of Light and Radiation". It has been approved by the Board of Administration and Division 2 of CIE. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by all with an interest in excellence in light and lighting. The information provided here is advisory, and not mandatory.

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CONTENTS

Summary 1
1 Introduction 1
2 Terminology 2
3 Goniophotometry of the light source 3
4 Determination and orientation of the optical beam axis 3
  4.1 Beam centroid 4
  4.2 Coordinate transformation 4
5 Determining the centre beam intensity 5
6 Determining the beam angle 5
7 Calculation of derived data 5
Annex A Example calculations for use in the validation of software 6
References 8

Summary

This document provides recommended methods for determining the optical beam axis of a directional light source; for performing a coordinate transformation to orient the luminous intensity distribution in the direction of the optical beam axis; and for determination of the centre beam intensity and beam angle(s) from the re-oriented luminous intensity distribution.

Many regional standards and regulations require a manufacturer of directional light sources to publish the beam angle (or beam angles for non-symmetrical sources) and centre beam luminous intensity of their products as well as derived data such as the useful luminous flux or zonal lumen values. However, these data are calculated from the optical beam axis and therefore their determination requires a precise, repeatable and unambiguous method of identifying the optical beam axis of a light source. This document provides guidance to this end.

1 Introduction

Directional light sources such as downlights and parabolic aluminized reflector (PAR) lamps are characterized by the beam angle, the centre beam intensity and, depending on regional requirements, derived data such as the useful luminous flux or zonal luminous flux values. These data are calculated with respect to the optical beam axis and therefore their determination requires a precise, repeatable and unambiguous method of identifying the optical beam axis of a light source. It should also be noted that, in the case of asymmetrical or complex beam patterns, there may not be a single value of beam angle that can adequately represent the distribution.

IEC TR 61341 “Method of measurement of centre beam intensity and beam angle(s) of reflector lamps” (IEC, 2010) provides guidance for the determination of the optical axis but was drafted primarily for halogen reflector lamps. Its extension to directional LED light sources raises questions due to their typically more irregular beam patterns. The determination of beam angle for irregular beam patterns as given in (IEC, 2010) is based on a conventional approach which may be unsatisfactory. Figure 2 of (IEC, 2010) indicates how to determine the beam angle within a plane through the optical beam axis. In this plane the optical beam axis is determined to be midway between the two 50 % points of the maximum intensity within the plane. This provides a single result for the direction of the optical axis within a plane, which is linked to the maximum intensity and not necessarily to the real symmetry. For complex distributions, this conventional method is applied for six (or more) different planes, leading to somewhat different directions for the optical beam axis in each of the planes, whereas this axis should ideally be unique. Hence the method provides neither a single clear direction for the optical beam axis of the source nor the real axis of symmetry.

Furthermore, the definition of optical beam axis given in (IEC, 2010) is the “axis about which the luminous intensity distribution is substantially symmetrical” (see also 2.2). While this definition serves adequately as a qualitative description of the optical beam axis, there is no guidance for what “substantially symmetrical” means in a practical or quantitative sense. This makes rigorous determination of the beam angle(s) and useful luminous flux, as well as other quantities such as centre beam intensity, problematic particularly for irregular beam patterns.

The purpose of this document is to provide guidance to manufacturers, laboratories and the general lighting community on how to unambiguously determine the optical beam axis and beam angle(s) of a directional light source in a manner that is as consistent as possible with the intention of (IEC, 2010). This is achieved in five steps:

- measuring the directional light source intensity distribution on a goniophotometer (Clause 3);
- determining the optical beam axis of the directional light source from the measured luminous intensity distribution and performing a coordinate transformation in order to produce a

luminous intensity distribution which is oriented in the direction of the optical beam axis (Clause 4);

- determining the centre beam intensity of the distribution (Clause 5);
- determining the beam angle (for symmetrical distributions) or two beam angles (for non-symmetrical distributions) from the re-oriented distribution (Clause 6);
- determining other derived data from either the original or the transformed distribution (Clause 7).

2 Terminology

2.1
directional light source

electric light source having at least 80 % luminous flux within a solid angle of π sr (corresponding to a cone with angle of 120°)

[SOURCE: IEC 60050-845:–[1], 845-27-070 – modified: "lamp" replaced by "light source"]

2.2
optical beam axis

axis about which the luminous intensity distribution is substantially symmetrical

Note 1 to entry: The optical beam axis is not necessarily the same as the lamp axis through the lamp cap or the lamp axis normal to a reference plane.

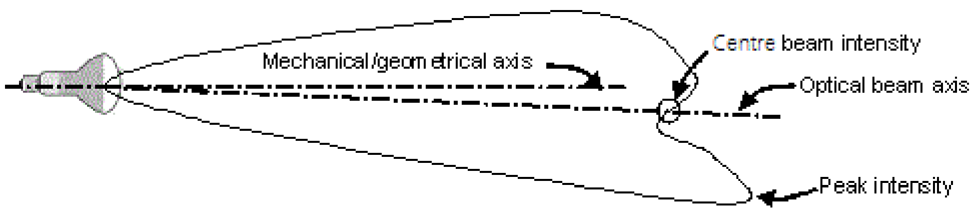

Figure 1 – Relation between optical beam axis, geometrical-mechanical axis, peak intensity and centre beam intensity

[SOURCE: IEC 60050-845:–[1], 845-27-071]

2.3
beam angle

angle between two imaginary lines in a plane through the optical beam axis, such that these lines pass through the centre of the front face of the device and through points at which the luminous intensity is 50 % of the centre beam intensity

Note 1 to entry: Beam angle is expressed in degrees (°).

Note 2 to entry: The beam angle is a full angle measure, not a half angle measure.

[SOURCE: IEC 60050-845:–[1], 845-27-072]

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[1] Under preparation. Stage at the time of publication: IEC CDV 60050-845:2018.

2.4
peak intensity

highest value of the luminous intensity in the optical beam

Note 1 to entry: The peak intensity is expressed in candela (cd).

[SOURCE: IEC 60050-845:–[1], 845-27-075]

2.5
centre beam intensity
I_c

value of the luminous intensity measured on the optical beam axis

Note 1 to entry: The centre beam intensity is expressed in candela (cd).

[SOURCE: IEC 60050-845:–[1], 845-27-073]

3 Goniophotometry of the light source

The light source is mounted on a goniophotometer with the photometric centre of the light source positioned at the reference point of the goniometer. The light source orientation is according to the relevant IEC product performance standard. Most types of directional light sources are aimed such that their mechanical axis is aligned with the geometric reference axis of the goniometer.

The environmental, electrical and stabilization parameters are according to the relevant IEC performance product standards. For LED and OLED sources, the provisions of CIE S 025 (CIE, 2015) also apply. In the absence of other guidance, the provisions of CIE 121 (CIE, 1996) or EN 13032-1 (CEN, 2012) can be used.

Given that the methods described here use a coordinate transformation that requires interpolating luminous intensity values within the distribution, the angular intervals should be as small as practicable. As a guide, intervals in azimuth angle should be 5° or smaller. For smooth distributions, intervals in elevation angle should be less than approximately 5 % of the rated beam angle (e.g. ≤ 5° for beam angles over 90°; ≤ 2,5° for beam angles between 60° and 90°; and ≤ 1° for smaller beam angles). For strongly asymmetrical or complex distributions the angular intervals may need to be even smaller.

NOTE Further research is needed to evaluate the effect of sampling interval on the uncertainties of the quantities evaluated in this document, particularly taking into account the effect of the coordinate transformation.

The luminous intensity distribution measured on the goniophotometer is referred to subsequently as the "original distribution". The peak intensity is the maximum luminous intensity value present in the original distribution.

4 Determination and orientation of the optical beam axis

This clause provides guidance for determination of the optical beam axis of a luminous intensity distribution and, once located, to perform a coordinate transformation to orient the luminous intensity distribution so that the optical beam axis coincides with the origin of the coordinate system (i.e. C = 0°, γ = 0° in a (C,γ) coordinate system).

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1 Under preparation. Stage at the time of publication: IEC CDV 60050-845:2018.

4.1 Beam centroid

According to 2.2 the optical beam axis is defined as "the axis about which the luminous intensity distribution is substantially symmetrical". In radiometry a common and convenient method of assigning an axis of symmetry is to calculate the centroid. The method of determining the centroid of a luminous intensity distribution was proposed by Bergen and Blattner (2017).

The centroid is a weighted average or centre-of-gravity equivalent. When determining the centroid, the direction of each luminous intensity element in the distribution is weighted by the luminous intensity and also the solid angle represented by that element.

Many people will be familiar with determining the centroid of a peak in a spectrometer, which is a simple one-dimensional dataset. Here the problem is more complicated because the luminous intensity distribution is given in a spherical coordinate system and the data are tabulated in a two-dimensional dataset. Section 2.1 in (Bergen and Blattner, 2017) provides detailed mathematics for determining the centroid from a luminous intensity distribution.

The optical beam axis lies in the direction corresponding to the centroid of the distribution, given by the angles C_{cent} and γ_{cent} in the (C,γ) coordinate system. The centre beam intensity is the luminous intensity in the (C_{cent}, γ_{cent}) direction.

4.2 Coordinate transformation

The next task is to perform a coordinate transformation, i.e. to rotate the distribution mathematically so that the optical beam axis aligns with the origin (i.e. C = 0°, γ = 0°). This is akin to orienting the lamp so that it is being aimed in a specific direction, except that it is being done mathematically instead of physically.

Rotating the data through an angle of C_{cent} is quite straightforward because this can be substituted directly as an offset in the C-plane. However, transforming the data with respect to the tilt angle in order to shift the optical beam axis from an elevation angle of γ_{cent} to the origin is not a straightforward process.

The most straightforward method of transforming the data with respect to the tilt angle is to use a conversion from (C,γ) to (B,β) coordinates, where the tilt can simply be applied as an offset in B-plane, and then the offset angle can be converted back to (C,γ). Formulae to convert from (C,γ) to (B,β) coordinates can be found in CIE 121-1996 (CIE, 1996), and an example of how to use these formulae to perform such a transformation can be found in (Bergen, 2012). Note that the latter reference includes an additional spin transformation, which is not being considered here.

The new luminous intensity distribution that has been re-oriented to align with the origin of the coordinate system is referred to subsequently as the "transformed distribution". The new luminous intensity distribution that has been re-oriented to align with the origin of the coordinate system is referred to subsequently as the "transformed distribution". While there is no fixed requirement, a reasonable convention is that the same set of C and γ angles contained in the original distribution are used for the transformed distribution.

At this point it is worthwhile comparing the luminous flux and the peak intensity of the transformed distribution with the luminous flux and the peak intensity of the original distribution. If there are significant differences between the two values, it may be that the sampling interval of the original distribution is not suitable for transforming.

5 Determining the centre beam intensity

The centre beam intensity is the luminous intensity value in the C = 0°, γ = 0° direction of the transformed distribution.

6 Determining the beam angle

Once the optical beam axis has been aligned with C = 0° and γ = 0° and the centre beam intensity has been obtained, the beam angle can be determined. The method of determining the beam angle of a luminous intensity distribution is the Ellipse Fit method proposed in Section 2.3 of (Bergen and Blattner, 2017). In each of the C-planes (half-planes) in the transformed distribution, the elevation angle, γ, at which the intensity drops to 50 % of the centre beam intensity, is determined. An ellipse can be fitted to these 50 % angles in a polar space where the polar angle is the C-plane and the radius is the 50 % angle. The fit usually delivers a confidence interval for all parameters which can be used in the calculation of measurement uncertainties, but also to determine whether the intensity distribution is truly elliptical. The dimensions of the long and short axes of the ellipse represent the long and short beam angles of the distribution. If these two values are not significantly different, they could be averaged to obtain a single value of beam angle; i.e. the distribution could be considered to have rotational symmetry.

This method produces results which are consistent with beam angles that would be obtained using (IEC, 2010) for symmetrical and basic asymmetrical distributions. Furthermore, for complex beam patterns the method of fitting an ellipse to the 50 % angles provides a “smoothing” effect which averages out noise.

7 Calculation of derived data

Derived quantities that are obtained from the whole of the luminous intensity distribution and are irrespective of the aiming, such as the total luminous flux, can be calculated using the original distribution as this will yield the lowest uncertainty.

Derived quantities that are obtained from only part of the luminous intensity distribution and are tied to the optical beam axis, such as the useful luminous flux and zonal luminous flux, can be calculated using the transformed distribution.

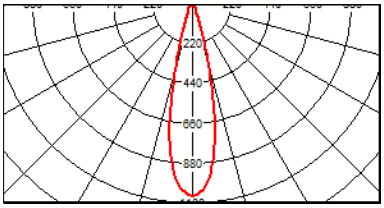
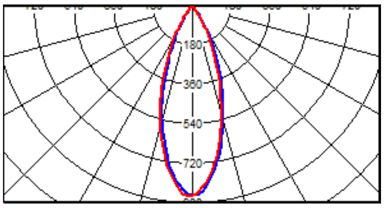
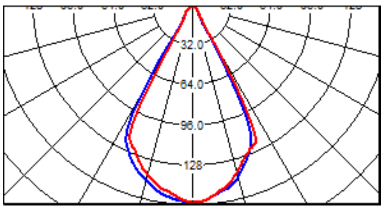
Annex A
Example calculations for use in the validation of software

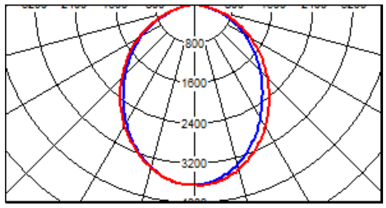
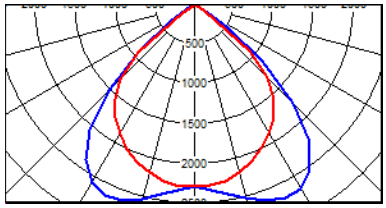
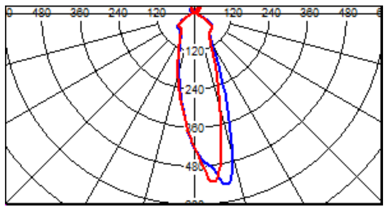
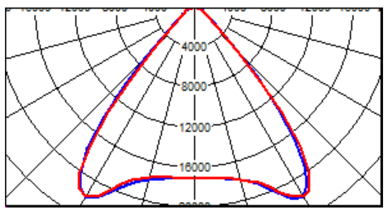
This annex contains sample luminous intensity distributions for use in validation of the determination of the beam axis, beam angle and centre beam intensity using the methods given in this document. There are nine distributions which have a range of relevant properties.

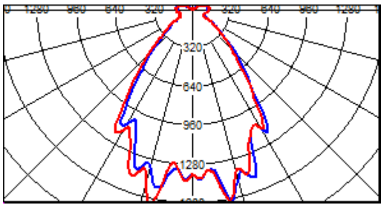
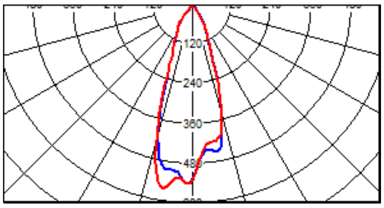
The photometric data files for the distributions, in IESNA LM-63 (.ies) and EULUMDAT (.ldt) formats, can be downloaded from the following link: http://files.cie.co.at/Example_LIDs.zip.

The results are summarized in Table 1. The third column shows polar curves with the 0°/180° plane in blue and the 90°/270° plane in red, which represent the original file data prior to transformation.

Table 1 — Summary of calculated data for nine sample luminous intensity distributions

#	Description	Curve (pre-transformation)
1	**Rotational symmetry, narrow beam, symmetrized data** Centroid azimuth: 0,0° Centroid elevation: 0,0° Ellipse long axis: 12,6° (Full: 25,2°) Ellipse short axis: 12,6° (Full: 25,2°) Ellipse rotation: 0,0° Axis length difference: 0,0 % Declare beam angle as: 25° Peak intensity (before trans.): 1 054,2 cd Peak intensity (after trans.): 1 054,2 cd Centre-beam intensity: 1 054,2 cd	
2	**Rotationally symmetric, narrow beam** Centroid azimuth: 291,2° Centroid elevation: 1,0° Ellipse long axis: 18,6° (Full: 37,2°) Ellipse short axis: 18,4° (Full: 36,8°) Ellipse rotation: 137,8° Axis length difference: 1,1 % Declare beam angle as: 37° Peak intensity (before trans.): 860,62 cd Peak intensity (after trans.): 859,34 cd Centre-beam intensity: 859,34 cd	
3	**Rotationally symmetric, intermediate beam** Centroid azimuth: 180,1° Centroid elevation: 1,3° Ellipse long axis: 28,5° (Full: 57,0°) Ellipse short axis: 28,4° (Full: 56,7°) Ellipse rotation: 42,8° Axis length difference: 0,4 % Declare beam angle as: 57° Peak intensity (before trans.): 157,40 cd Peak intensity (after trans.): 157,40 cd Centre-beam intensity: 157,21 cd	

4	**Rotationally symmetric, wide beam** Centroid azimuth: 164,4° Centroid elevation: 0,7° Ellipse long axis: 49,6° (Full: 99,3°) Ellipse short axis: 47,0° (Full: 93,9°) Ellipse rotation: 89,5° Axis length difference: 5,7 % Declare beam angle as: 99° x 94° Peak intensity (before trans.): 3 635,0 cd Peak intensity (after trans.): 3 631,1 cd Centre-beam intensity: 3 626,7 cd	
5	**Quadrantal symmetry** Centroid azimuth: 356,1° Centroid elevation: 0,2° Ellipse long axis: 49,8° (Full: 99,5°) Ellipse short axis: 49,6° (Full: 99,3°) Ellipse rotation: 172,1° Axis length difference: 0,2 % Declare beam angle as: 99° Peak intensity (before trans.): 2 675,1 cd Peak intensity (after trans.): 2 674,5 cd Centre-beam intensity: 2 277,4 cd	
6	**Off-axis lamp** Centroid azimuth: 28,4° Centroid elevation: 6,3° Ellipse long axis: 15,9° (Full: 31,9°) Ellipse short axis: 13,7° (Full: 27,4°) Ellipse rotation: 146,6° Axis length difference: 16,5 % Declare beam angle as: 32° x 27° Peak intensity (before trans.): 551,66 cd Peak intensity (after trans.): 549,33 cd Centre-beam intensity: 506,08 cd	
7	**Depressed centre** Centroid azimuth: 159,0° Centroid elevation: 0,2° Ellipse long axis: 43,4° (Full: 86,8°) Ellipse short axis: 43,0° (Full: 86,1°) Ellipse rotation: 0,6° Axis length difference: 0,9 % Declare beam angle as: 86° Peak intensity (before trans.): 21 906 cd Peak intensity (after trans.): 21 863 cd Centre-beam intensity: 17 049 cd	

8	**Complex #1** Centroid azimuth: 289,3° Centroid elevation: 1,5° Ellipse long axis: 40,6° (Full: 81,3°) Ellipse short axis: 39,5° (Full: 78,9°) Ellipse rotation: 53,9° Axis length difference: 2,9 % Declare beam angle as: 80° Peak intensity (before trans.): 1 664,1 cd Peak intensity (after trans.): 1 646,0 cd Centre-beam intensity: 1 396,6 cd	
9	**Complex #2** Centroid azimuth: 235,9° Centroid elevation: 1,5° Ellipse long axis: 17,8° (Full: 35,6°) Ellipse short axis: 17,7° (Full: 35,3°) Ellipse rotation: 112,6° Axis length difference: 0,7 % Declare beam angle as: 35° Peak intensity (before trans.): 560,52 cd Peak intensity (after trans.): 559,91 cd Centre-beam intensity: 549,68 cd	

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