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LINEAR LAMP SIMULATIONS FOR NEAR FIELD REFLECTIONS

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Abstract: *Linear lamps (fluorescent or LED) represent an option for specific applications. Fluorescent lamps maintained some important advantages, even if energy efficiency is in discussion. For near field simulations – coves, luminaires – the usual mathematical representation are not sufficient. An IES file is valid for normal interior lighting, not for near field, and the traditional theory don't have any approach. The paper proposes a method to solve these limitations, and specific MATLAB solutions are presented. Measurements in the field, for the test problem, validate the method.*

Key words: *form factor, cylindrical reflector, diffuse reflections.*

1. Introduction

From the beginning, the linear lamps where studied, due their large usage. In [1], a classical monographic book, a special chapter was dedicated (8.1.2.2, pg.200). From the first view, important limitation of calculus method are visible, based on analytical method: the calculation surface must be considered parallel or perpendicular with the luminaire, for a discontinuous lamp line some supplementary approximations are imposed, the calculus is valid for three luminaire classes, not for the general situation of an linear lamp, and the integration was possible only for points situated at the end plane of the luminaire. All these limitation gives a small relevance to these theoretical approach. Even for the most recent software, in DIALux EVO, we discover some important nonconformities, generated by the photon method of calculus and the necessity to have a short computational [2]: "…despite the large number of photons, small surfaces are not hit or are insufficiently hit by the photons". This is exactly the situation we are discussing in this paper. Also in [2] we could find a very disturbing statement which also comes from the calculation method:

"- The rule of photometric distance no along applies in near-fields;

- The number of photons used is restricted by the available storage capacity and the accepted calculation time;

- Any situation simulated by software represents a simplified model of physical reality and can therefore not provide 100% calculation accuracy."

All these arguments serve as a starting point for this research.

2. The Relevance of Linear Lamp for the Interior Lighting Systems

The LED's progress, in the last years, don't eliminate the role of the linear lamps, fluorescent or not. In [3] we discover the problems in describing the luminous distribution of the same T5 fluorescent troffer

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luminaire, tested at two different laboratories. Trying to discover a better match between measurements, “an iterative process whereby larger angular intervals are used initially and then smaller localized scans with smaller intervals are used to hone in on the maximum value of the lighting intensity of the luminaire.” The author [3] uses “an initial interval of 0.5°, and then a smaller interval of 0.1° within a localized area around where the maximum lighting intensity is encountered”. We conclude from here that the for the near field geometry, the usual IES files are not sufficient in accuracy. Also in [3], starting from “the work of several CIE Division 2 Technical Committees (e.g. TC2-62) highlights the need to compare the measurements made on both far-field and near-field goniophotometers”, gives us the explanation consist in “simple comparison of the luminous intensity measurements, however, can lead to large errors where there is a steep luminous intensity gradient when the only difference between the two sets of measurements is a small discrepancy in alignment.”

A supplementary strong argumentum is available in [4], obtained from light-pipe goniophotometry: “at the present time there are no standards for the measurement of the luminous intensity distribution of hollow light guides (HLG). The reason for this lack is that the length of hollow light guides (4 m÷30 m) makes it impossible to measure light-pipes with conventional photometric apparatus. New quantities for describing the lighting characteristics are defined. They are related to common lighting quantities. For a photometric description, light-pipes are divided into several parts (segments), each of which is treated as a single luminaire while being measured.” Searching for the similarity with our case, we discover immediately, also in [4]: “The problem occurs, if the luminous intensity distribution of these systems needs to be measured. The conventional photometric approach is based on the inverse square law:

$$E = \frac{I \cdot \cos\theta}{d^2} \tag{1}$$

This law is only valid for point light sources, which do not exist in reality. Therefore the measurement distance has to be chosen in such a way that the error due to the size of the light emitting area is acceptable...The measurement distance depends on the following quantities:

- size of the light emitting surface
- luminous intensity distribution
- maximum acceptable error
- size of the photocell.

Additionally, the measurement data cannot be used for photometric calculations in small rooms i.e., rooms that are so small that the inverse square law is not applicable.” This conclusion is in general well accepted, we consider it just to underline our approach.

More recent research [5] introduce the near-field representation of light sources in lighting design for more accurate predictions when luminaires based on LED arrays with focusing optics are involved.

But the problem of near field lighting it is not only theoretical. In [6] we retrieve a discussion about “determination of the effect of luminaire size and illuminance on the assessment of harshness–softness attribute of shadows.” The lightness–darkness attribute of self-shadows is dealt with by the term modeling in the lighting literature. And this is already a highly qualitative criteria, more than energy efficiency, as in the case of the coves.

3. Objectives

The simulation will be focused on a linear fluorescent lamp, T8 Master TL-D Super 80 36W, with luminous flux 3350 lm. The lamp is working on a prismatic reflector, with Lambertian reflectance. The target surface is considered also at short distance, at 1,2m from the lamp. The geometrical configuration is available in Figure 1:

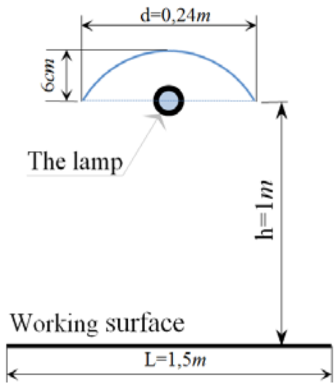

Fig. 1. *The geometrical configuration of the test problem.*

The length of emissive surface of the lamp is 1175 mm, and the working surface has the dimensions 1,5 x 3m, with central symmetry toward the lamp. The nominal luminous excitance of the lamp is 3,49 lm/cm^2, and a luminance of 11110 cd/m^2.

In order to build the model, some measurement was performed, to determine the limit of the near field. The illuminance was measured at distance from 0 to 40 cm, for a full exposed linear lamp (1,2m in Figure 2), for a small segment of the lamp (2,4 cm in Figure 2) and a segment of 10 cm of the lamp (10 cm curve in Figure 2). The values of the curves are calculated from Eq. (1), considering $\cos\theta = 1$ and searching the invariant:

$$E \cdot d^2 \cdot k = const. \qquad (2)$$

Where k is a scale factor, particularized for every curve from Figure 2 one observe that the inverse square law (1) is valid over 22 cm for the shortest linear lamps (2,4 cm and 10 cm) and over

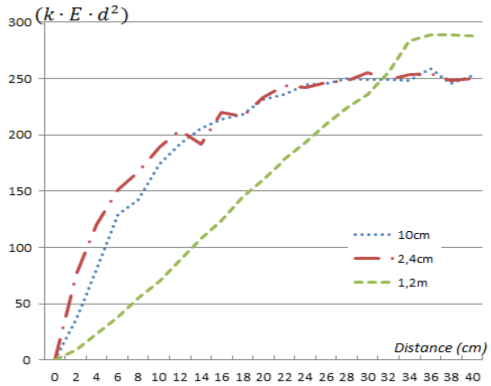

Fig. 2. *The inverse square law validation domain, due equation (2).*

34 cm for the full length of the lamp. These measurements will be used to verify the main hypothesis and MATLAB function, created by the author. After this validation, the method will be extended to other lighting systems, as in Figure 1.

4. Mesh Generation and Method Validation

The luminous model include the linear lamp, full length, working on a planar surface. The diffuse (Lambertian) emissive surface will be considered only for direct visibility between inferior cylindrical surface and horizontal plane. One prepare a fragment of this inferior cylindrical surface, to illustrate the matrix element of the mesh, in Figure 3:

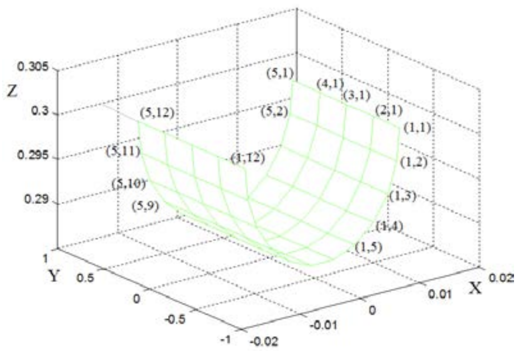

Fig. 3. *The points arrangement for mesh generation*

Off course, the number of finite elements will be larger for the real simulations. Knowing the position of the points, the coordinates of every point will be calculated with:

```
XL(j,i)=R*cos((i-1)*pi/11);
YL(j,i)=1.170/2-(j-1)*1.170/4;        (3)
ZL(j,i)=.30-R*sin((i-1)*pi/11);
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In (3), *R* is the radius of the lamp (13 mm) and 1.170 is the length of T8 lamp, and the units for dimensions are in *m*.

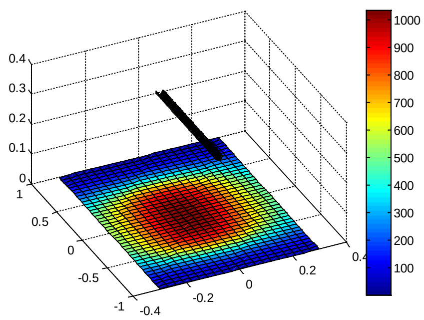

Fig. 4. *The relative position of the T8 lamp – 30 cm high, with the illuminance (lx) on the working plane*

In this moment one have the model ready to calculate the illuminance produce by the linear lamp, for distance from 4 *cm* to 40 *cm*, obtaining a comparison with measurements, in Figure 5:

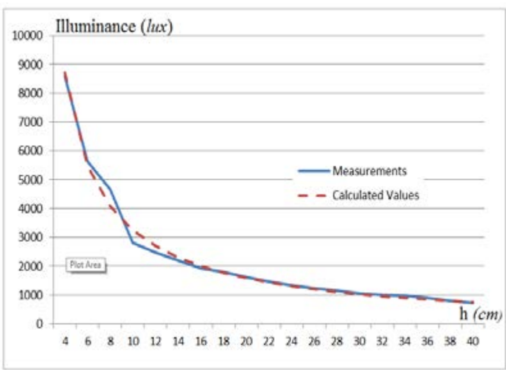

Fig. 5. *Comparison between measurements and calculated values, lighting scene corresponding to Figure 4*

One retrieve a perfect match, with some differences due the wrong positioning of the sensor. On the near field the coincidence is satisfactory and it serves to validate the spatial model of the lamp. The measurement were performed on the optical axis of the lamp (for the maximum illuminance), because in any other direction the illuminance is a consequence of the incidence angle. The main results will refer to the near field consisting in a cylindrical reflector for the lamp (Figure 1).

5. Results and Discussions

For a detailed model of the linear lamp with cylindrical reflector one must prepare the mesh for the next elements:

- the inferior part of the lamp, working directly to the inferior working plane;
- the superior part of the lamp, lighting directly the cylindrical reflector;
- the cylindrical reflector, with his real position (6*mm* in Figure 1) and length (1000 *mm*), positioned symmetrical in rapport with the lamp. This length has no special relevance, was a result of the manufacturer process of the mock-up ;
- working plane;

After all these steps, the result will be obtained by:

- model aggregation, to obtain the correct positioning between all these components;
- processing the ray tracing, for the direct illuminance from the lamp, the direct illuminance of the reflector (original contribution, if considering the particular shape of the reflector) and the reflected flux by the reflector to the working plane (also an original contribution of the paper).

All these steps are imposed because MATLAB has not specialized toolboxes. The advantages are in the total control of the calculus, without any approximation.

5.1. Mesh Generation for the Inferior End the Superior Part of the Lamp

This is a particularity of author's method, giving the possibility to differentiate the calculus in function by the visibility between surfaces. In other cases, this is solved by a supplementary array with zeros or ones element, indicating the relative visibility between elementary surfaces.

The mesh generation is similar with Figure 3, and the visualisation has the role to verify the geometry and the correct property allocated to the elements of the lamp. In Figure 6. One present a simplified mesh, with a small number of the element..

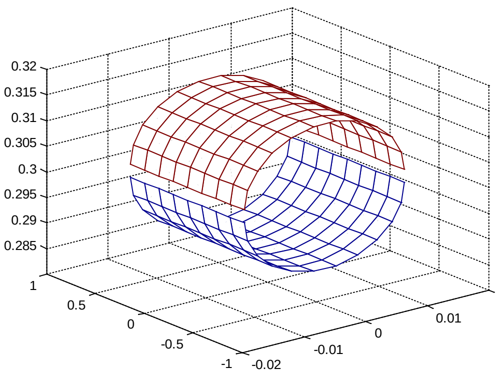

Fig. 6. *Mesh generation for the inferior and superior surface of the lamp (illustrated with a small number of elements).*

A supplementary interspace was imposed and it is visible in Figure 6., but only for the preparing phase of the lamp's mesh.

5.2. Mesh Generation for the Cylindrical Reflector

A cylindrical reflector has a profile determined by a different objectives, not discussed in this paper. The mesh generation for a particular shape of the reflector could be realized introducing the coordinates of the profile, all other coordinates being calculated. In this manner, the profile of the reflector could be as close as the real one, not only theoretical curves. In Figure 7, the relative position between linear lamp and cylindrical reflector are already implemented.

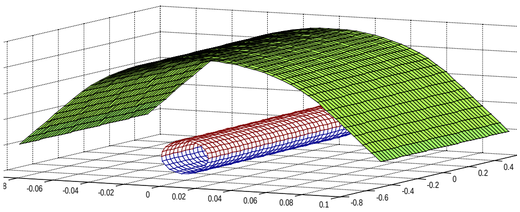

Fig. 7. *The cylindrical reflector, added to the lamp.*

In the same figure, one observe that the interspace was removed. Also, the scale of the axis are not the same (units are in *m*). In Figure 8. one observe the similarity with the mock-up with the mesh.

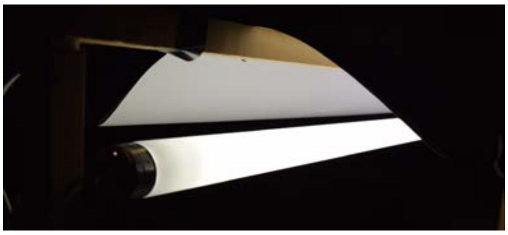

Fig. 8. *Mock-up detail with the lamp and the reflector.*

5.3. Working Plane and Model Aggregation

The lighting scene used for the general validation of the method include also the working plane, on which the illuminance could be measured (Figure 9).

Fig. 9. *The image of lighting scene used for the general validation of the method*

In this moment one have the situation announced in Figure 1, and the final necessary element is the working plane, at a distance of 1 *m* below the lamp, as in Figure 10:

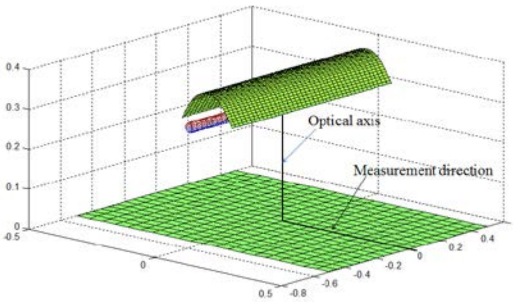

Fig. 10. *The aggregated model for the lighting scene used for the general validation of the method*

After the global model is ready, the original MATLAB function are used to calculate the illuminance on working plane. This values include the inter-reflection from linear lamp, with spatial geometry and the cylindrical reflector and are presented in Figure 11:

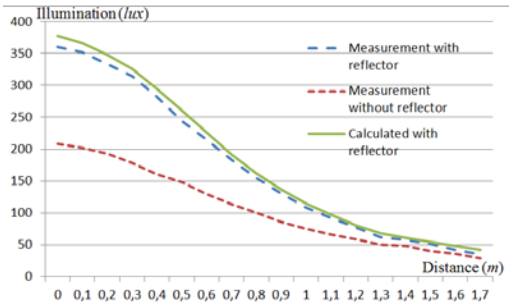

Fig. 11. *The final measurements for method validation for near field inter-reflection.*

One observe a systematic difference, acceptable because the reflectance of the reflector was imprecise determined. Supplementary, the effect of the reflector is obvious, comparing 360 *lx* with the illuminance produce by the lamp (208 *lx*), without reflector.

6. Conclusion

The traditional analytical methods dedicated to linear lamp have important limitations. Numerical approach based on finite element, developed by the author, could be apply for spatial modeling of the lamp and also for the reflection in near field of the lamp.

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