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Research Paper

Triangulation grids and hierarchical structures of the models in calculation of LED modules

Baynev Vitaly [1] *, Fedosin Sergej [2]

[1] graduate student, Department of Automated information processing systems and Management, Institute of Electronic and Light Engineering, National Research Ogarev Mordovia State University, Saransk
[2] Professor, Candidate of Science (PhD) in technology, Department of Automated information processing systems and Management, Institute of Electronic and Light Engineering, National Research Ogarev Mordovia State University, Saransk
**Corresponding author E-mail: bw14@mail.ru*

Abstract

The paper considers the problem of designing modern lighting devices and optical systems. Analysis of the development of lighting devices shows that the main stage in their development is the calculation of the optical system. The results of this calculation largely determine the lighting and functional characteristics of light devices. The efficiency of existing methods of calculation are not always satisfied of the development. Application and development of specialized software for the calculation and simulation of light devices significantly facilitates and speeds up the process of their design. The paper presents a mathematical model developed by the software system, described in the hierarchical structure of the simulation geometry LED modules and light devices. Light device in a hierarchical structure represented by the root element of the tree, where the housing, the optical system, a light source, protective glass, suspension assembly, and others are nodes. The affine transformation using to calculate of the absolute position of nodes. The geometry of the nodes is modeled using triangulation grids. To simulate smooth surfaces in a triangulated mesh introduced an additional element - the rib. The software package is carried out modeling of LED optical systems and luminaires based on them using surface models, ray tracing and calculation of photometric body.

Keywords: *LED; LED Module; Optical System; Lens; Reflector; Light Device; Calculation; Photometric Body; Program; Hierarchical Structure; Modeling.*

1. Introduction

The design of lighting devices (LD) is a very important and urgent task for the modern lighting industry. This is due to the fact that the use of lighting devices with a high efficiency ratio can significantly increase the efficiency of lighting installations of mass use and reduce their energy consumption. The development of lighting devices is largely determined by the improvement and development of methods for their lighting design. The results of this calculation largely determine the shape and dimensions of the optical system and the entire LD, as well as its lighting parameters, which in turn depend on the field of device application. The lighting design is based on solving a sequence of direct problems of calculating the SP, that is, the determination of light distribution of the LD with known parameters of the optical system and the light source. It is known various methods for solving the direct problem of calculating the LD based on the method of elementary mappings, balance of flows, and numerical-ray methods [1]. Optical calculation, or calculation of the optical system, is the main stage in the development of a lighting device, since it determines not only the technical, but also the consumer properties of the device being developed. As a result of its implementation, the overall and aberration characteristics, parameters of the optical system and radiation sources that provide the specified photometric characteristics of the lighting device are determined. Optical calculation allows simulating the interaction of light beams with the system of lenses, reflectors, etc. [2-3].

At present, various numerical and iteration methods are used to calculate the reflecting (refracting) surfaces of a free form, which allow optimizing the shape of refractive surfaces from the condition of forming a given light distribution. The effectiveness of existing methods is not high enough, and the problem of calculating optics to form a given lighting is still of great practical importance [4]. In most cases, the calculation of optics is a time-consuming and labour-intensive process. If the optical calculation is performed incorrectly or with errors, it will only become clear after all the other design and manufacturing stages have been completed, when all the planned time and material resources have already been spent. Therefore, it is implied the use of computer technology and the use of specialized software that allows the engineers avoiding time-consuming calculations, multivariate analysis and a large amount of graphic works at the present stage. Such automated systems for calculating and modeling the lighting devices using modern software significantly expand the possibilities of the modern lighting technology [5-7].

2. Description of the mathematical model

Hierarchical structures in modeling the geometry of lighting devices. When solving a wide range of problems, complex objects are often represented as a set of simpler ones, which in turn are also divided into smaller components. This process is carried out until the required degree of detail is achieved with the object representation in the form of a tree (hierarchical) structure. This ap-

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proach is very convenient and optimal for the calculation and design of many technical systems, which can also include the LD. In this regard, it was decided to consider the LD also in the form of a hierarchical structure [8]. In this case, the root element of a tree is directly represented by the LD itself; there is a housing, an optical system, a lighting source, a protective glass, a suspension assembly, an electrical engineering, etc. at the next level of the hierarchy. Each of these parts in turn can be presented in more detail. For example, an optical system - in the form of a set of reflector, lens and diffuser. The elements in this structure are the logical nodes. Child nodes inherit the values of the properties and parameters of the parent nodes. That is, if we hide a node, then all of its descendants will also disappear. Similarly, if the child node does not explicitly specify the material type, it is inherited from the parent one. Also, each parent node specifies a geometric basis for the child nodes. All coordinates are relative. By moving, rotating or scaling any node (for example, a lighting source) in the space, its components (bulb, cap) will be also moved, rotated and scaled with it, forming one indivisible entity.

Triangulation grids with geometric modeling of lighting devices. It is used the affine transformations to calculate the absolute coordinates of nodes. Logical nodes at lower abstraction levels should be represented in the form of real objects, for example, reflecting surfaces, light-emitting elements, heat-conducting plates. The geometry of such nodes is modeled with the help of triangulation grids. The triangulation grid itself consists of vertexes and faces. The vertexes define the position of points in space, the faces connect three given vertexes by a planar triangle.

There is the problem of modeling smooth surfaces with lighting calculations. They include: paraboloids, spheres, cylinders, since in most cases such forms have optical systems that specify the required light distribution [9-10]. However, if the triangulation grid is assumed to be plane, when the rays are traced, the rays will be reflected from it by beams. In this case, the result of the light distribution calculation will not correspond to reality: there will be bursts and dips on the surface of the photometric body where a smooth area should be obtained. Only a significant increase in the triangulation density (that is, an increase in the number of faces per unit area) can partially relieve the appearance of this undesirable effect.

In this regard, the third component of the triangulation grid - the rib - was introduced. It connects two vertexes and points to adjacent faces how to calculate the normal vectors in the connected vertexes. To do this, each edge specifies either a sharpening, or a smooth transition between adjacent faces. In the first case, the normal vectors at both vertexes will be perpendicular to the planes of the corresponding faces. In the second case, the normal vectors at these vertexes will coincide for each face and be calculated as the normalized arithmetic mean of the vectors perpendicular to the faces. In the case of a smooth transition for these faces, the direction of the normal vector will depend on the point location on the triangle surface. Thus, the application of this expanded method of specifying a triangulation grid with the use of edges makes it possible to considerably simplify the process of approximation of smooth surfaces without any increase in the grid density itself.

Formation of the resulting model. Many LD have the same elements (for example, LEDs). In order to avoid creating and storing the same triangulation grids for each model node, we turned the grid's dependence on the node: Each node points to a grid whose geometry it uses. Now it is enough to simulate one or several basic forms (details), create and arrange logical nodes in space and bind the form data to these nodes. As a result, we obtain a model consisting of the same elements. Correcting the shape of one detail, the forms of the others will synchronously change. The practical application of such a scheme is demonstrated by the example of the LED module (fig.). However, when the rays are traced, it is necessary to denormalize such a structure by duplicating nodes and constructing one global triangulation grid. Thus, the given basic methods for constructing and organizing geometric models are fully applicable to modeling the structural elements of the LD. This greatly facilitates the process of calculating, researching and analyzing the devices being developed.

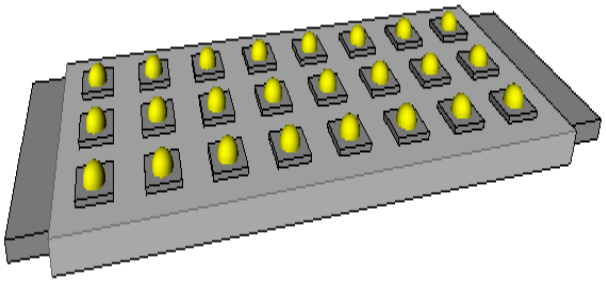


Fig. 1: LED Module Model.

3. Practical implementation of the task of modeling the LD

The models described are used as the basis for the developed software package, with the help of which the LED optics and devices based on it are modeled [11-13]. This package allows, according to the known light distribution of the LED and the required light distribution of the device, simulating the geometry of the lens with a radiating surface providing a comfortable visual perception and easily reproduced by the modern production methods. The following parameters are used as initial data for the calculation: the light intensity curve (LIC) of the LED, the standard (required) LIC of the device, the refractive index of the optics material, the overall dimensions of the lens [13-15].

Fig. 2 shows an example of calculating the light distribution of the LED module, where the photometric body is shown. The light intensity curve in the upper right corner is the cross section of the photometric body with the given plane. By investigating and analyzing the data obtained on light distribution, the designer tries to select such parameters of the optical system model in order to obtain the required characteristics of the lighting device. Fig. 3-4 shows the process of constructing a TIR-optics model for a single LED, ray tracing for a given type of surface to obtain a photometric body.

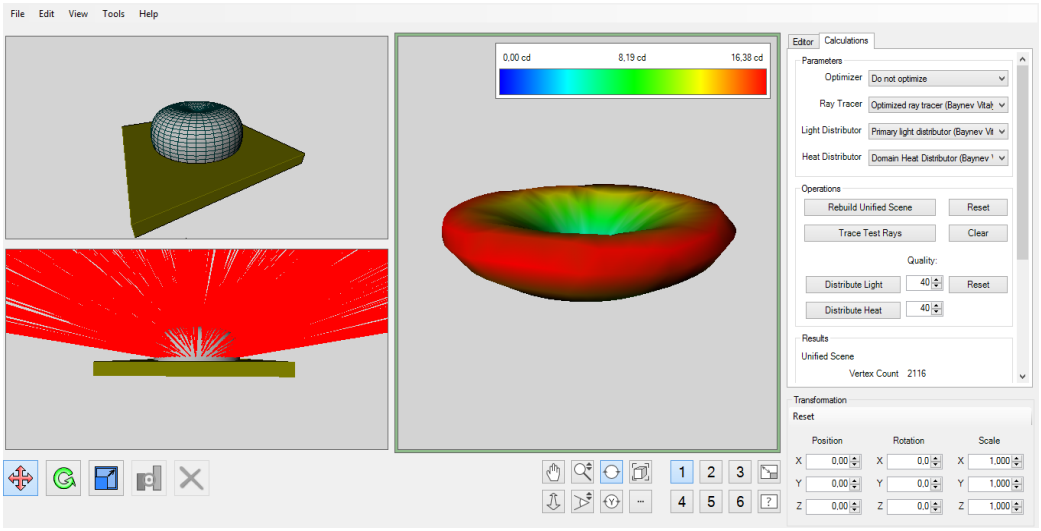


Fig. 2: Models and Light Distribution of the LED Module.

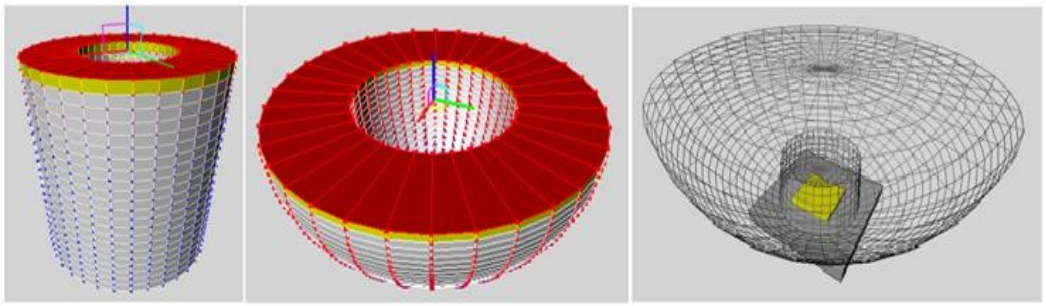


Fig. 3: Construction of the TIR-Optics Model for the LED.

4. Summary

In modern lighting engineering, calculation and modeling of lighting characteristics of the LED modules and lighting devices is an urgent task. The developed program allows to considerably facilitating the process of designing the optical LED systems and improving their quality. Here the lighting device as a complex product is viewed in the form of a hierarchical structure in the form of parent and child nodes, the geometry of which is modeled with the help of triangulation grids. To smooth the surface of the optical element and the photometric body, an edge was introduced as an additional element of the triangulation grid. Such a task of a triangulation grid makes it possible to substantially simplify the process of approximation of smooth surfaces. Also, in the developed program, the formation of the resulting model was implemented on the basis of the basic forms and the logical tree, which ensures a synchronism of the changes in the forms of the same elements. With the help of this software package, we simulated the LED secondary optics by developing the surface models, ray tracing for a given type of surface with obtaining a photometric body.

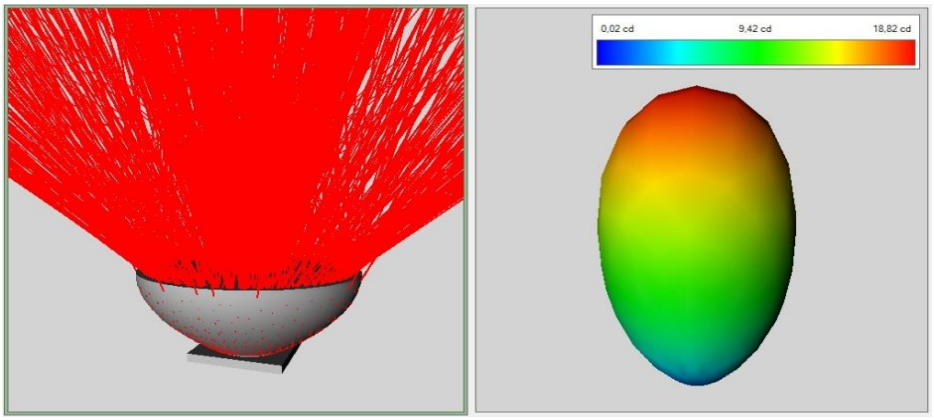


Fig. 4: The Result of the Light Distribution Calculation for the LED Model with TIR-Optics.

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