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Simulation and study of optical systems based on LEDs

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Abstract. The paper considers the problems and the ways of reaching energy efficiency in lighting. The features of lighting engineering calculation, the computer modeling of modern light devices based on light-emitting diodes and their optical systems are also considered. The development of modern LED lighting systems is associated with the use of software. The article describes the developed software system that allows to develop the models of optical systems, to perform ray tracing and to design the spatial distribution of light flux. The modeling of optical systems is described using the example of secondary LED optics for street lighting fixtures. They performed an experimental study of the main lighting and thermotechnical characteristics of lens systems, created by 3D prototyping.

Key words. Modeling, optical system, lighting device, secondary optics, LED, lens, photometric body, program, tracing.

1. Introduction

The problems of industrial product quality provision and energy efficiency increase have one of the highest priorities in Russia and in the world [1]. This fully applies to modern lighting, which currently consumes about 20 % of the world electricity consumption, and it will only increase due to ever-increasing needs. The increase of energy saving and energy efficiency in the field of lighting is aimed primarily at the prohibition of incandescent lamp production and consumption, the modernization of lighting systems and an active introduction of LED technologies [2–3]. Energy saving is also very important in the production of many possible optical and electronic devices and has become the focus of attention recently [4]. LED lighting systems allow to implement many tasks in the field of modern artificial lighting. The use of LEDs for outdoor, industrial and architectural lighting will grow at higher rates than in other areas of their traditional use (indications, lighting

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systems, etc.). The main trends for LED lighting equipment improvement is the increase of light output and service life at cost reduction. A wide application of LED makes relevant the calculation and the design of lighting systems that have high light efficiency and wide possibilities of lighting technical characteristics control.

In modern lighting engineering, the calculation and the modeling of LED lighting characteristics of lighting devices (LD) is an actual task. The results of this calculation largely determine the shape and the dimensions of an optical system and an entire LD, as well as its lighting parameters, which in its turn depend on the field of a device application [5–7]. The calculation of an optical system (OS) is the main stage in LD development, the result of which is its overall and photometric characteristics determination. Light engineering calculation of optical systems is based on a sequence of direct problem solution for LD calculation, i.e. the determination of LD light distribution under known LD and light source parameters. There are various methods for this problem solution, based on the methods of elementary imaging, the balance of flows, the numerical-ray methods, etc. [2]. In many cases, when a LD is used in lighting systems, a special secondary optics is needed. It serves to develop a set light distribution [4]. Nowadays, secondary optics are produced with a variety of light intensity curves (LIC) influenced by the type of surface and optics geometry and the characteristics of LED (luminescence power, size and angle).

2. Method

The calculation of OS elements consists of several stages. First, a light source model is created, a light distribution is set, a choice or a development of an optical element form and design is performed. Then, the simulation and the optimization of an obtained system are carried out by characteristic analysis, parameter adjustment and a direct optimization to obtain a final result [8]. The use of computer technology makes it possible to avoid labor-intensive manual calculations and a large amount of computational and graphic works. And many stages of their development can be fully automated with the use of a specialized software for modeling, the analysis and the optimization of optical systems.

The mathematical model is developed, which is used as the basis for LightModeling software package developed for modeling purposes. This program allows you to create three-dimensional models of optical systems and conduct the analysis of illumination distribution, taking into account the reflection, the absorption and the diffraction of light. Special elements of secondary optics have been developed for the use in street and road lighting relatively recently. The use of such lenses can greatly simplify the task of LED fixture design for street and road lighting, while they can be installed instead of conventional ones with discharge lamps, without the change of support configuration.

3. Results

It is very important that the elements of the secondary optics are accessible with the required parameters of a selected type of LED for the manufacturers of LED outdoor lighting. Street lighting, as a rule, requires the development of a specific LIC, a typical shape of lenses and their LIC for such lighting are shown in Fig. 1. A similar function is performed by the LD with multilenses.

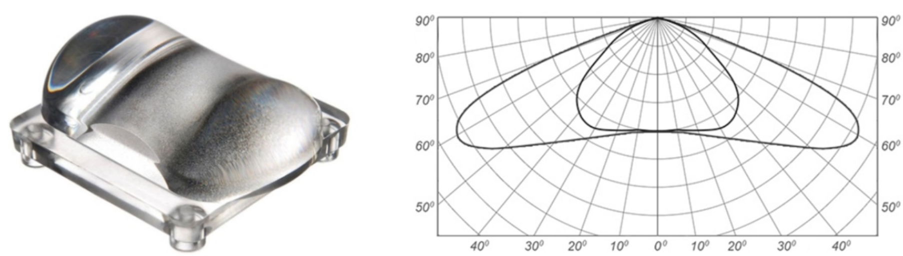

Fig. 1. Typical forms of lenses and LIC for outdoor lighting fixtures

The algorithm of OS modeling by the use of the software package was described in [5]. Figures 2–3 show the process of LED optics design for a street lighting fixture. The following is shown here: the working window of the program with the LED module (LM) and the functional of specifications for used materials (Fig. 2), SD model with secondary optics, its photometric body and LIC (Fig. 3) and LM assembly model (Fig. 4).

3.1. LED module prototyping

In order to test the adequacy of the developed LM for the LED road lighting fixture, the prototyping was carried out (the creation of prototypes or a system running model to test the feasibility of their implementation). One of the most common formats for a prototype model provision is STL format, which is used for 3D modeling and the use in 3D printers. The developed software allows to export the calculated data to many formats, including OBJ format for standardized files containing 3D objects. Further design was carried out in 3DS Max program, namely, the export to the previously described STL format for a 3D printer. The final LM model for prototyping has the following overall dimensions: 18.8×11.2×6.35 mm. A rapid prototyping unit (3D printer) ULTRA 3SP was used was used for prototyping. A key feature of this 3D printer is the ability to use transparent E-Glass material, which allows to prototype transparent lighting components (protective glass of complex shape, lenses, optical elements, etc.). After the performed works, the model, obtained through the use of 3D printing, is completely ready for the production of a silicone mold with the subsequent pouring of polyurethane into it.

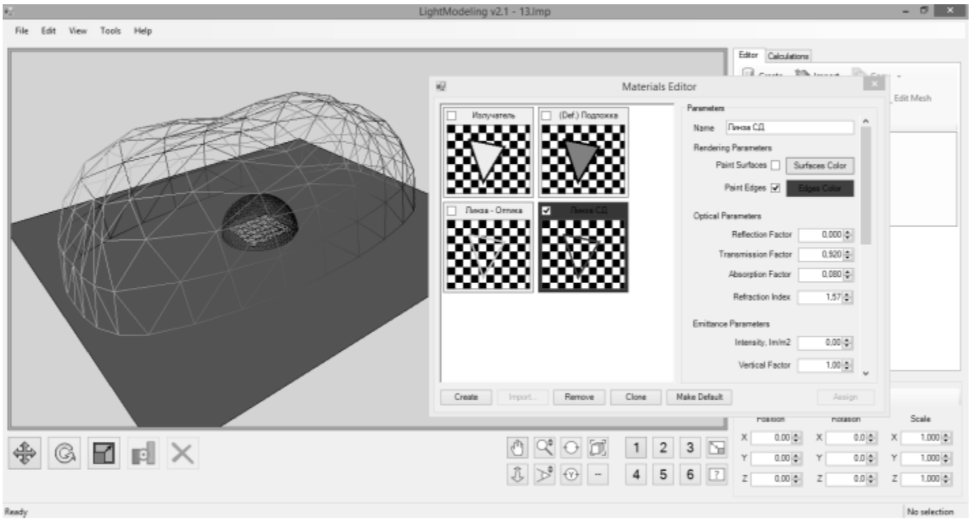

Fig. 2. Projecting of material characteristics in design process

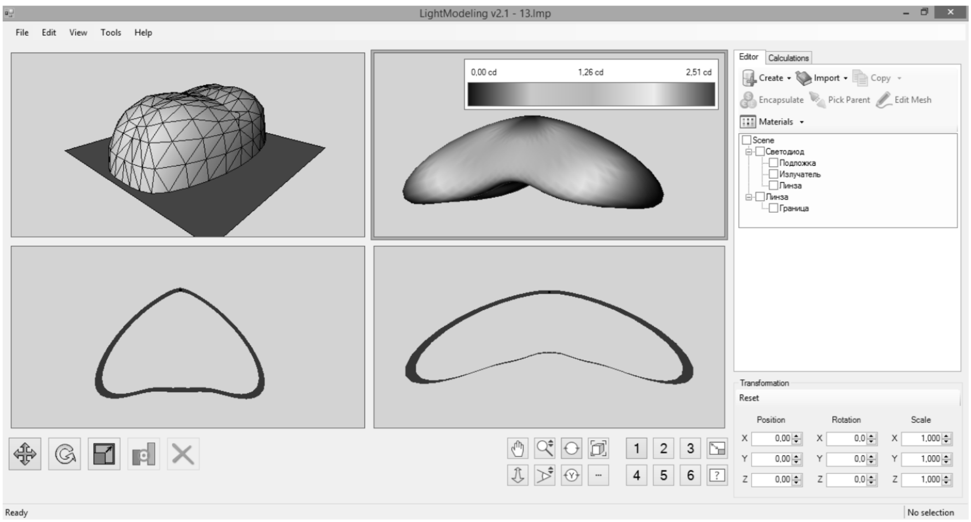

Fig. 3. Light distribution modeling from LM

3.2. Experimental study of LED module lighting characteristics

The most significant characteristics of LM are light distribution and thermal mode. The measurement of light intensity and luminous flux spatial distribution as a derivative can be performed with a goniophotometer (GO-2000A distribution photometer) most accurately. The processing of test results is performed using the supplied software GOSoft V2.0 in an automatic mode, which is displayed in real time. The result of the experimental LM measurement on a goniophotometer was a

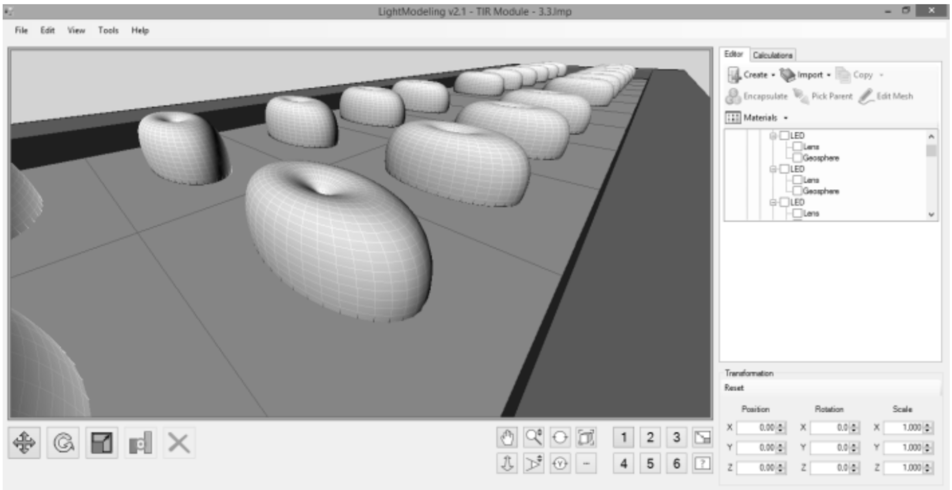

Fig. 4. LM assembly

photometric body and LIC (Fig. 5), which meet the requirements of street lighting.

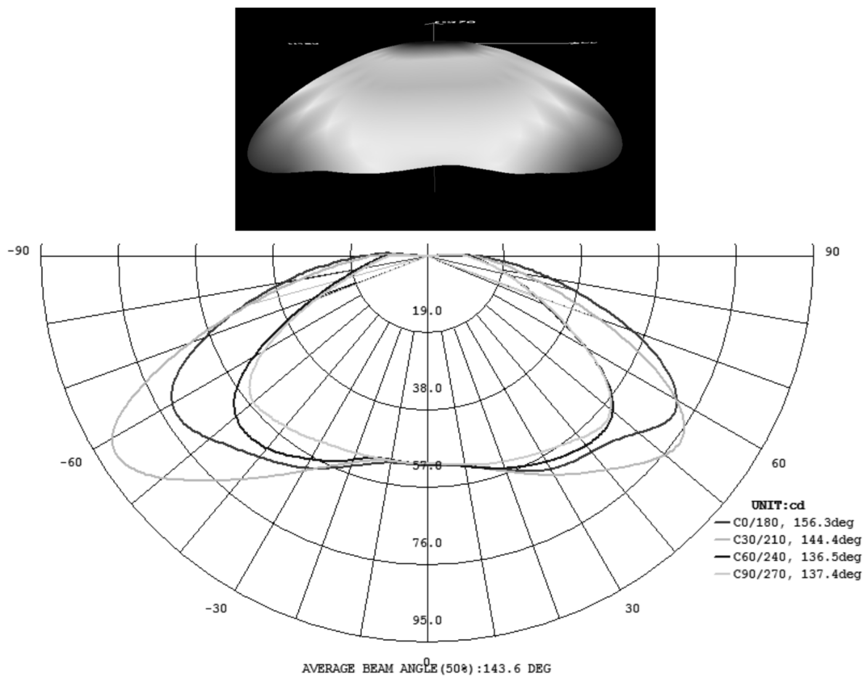

Fig. 5. The photometric body and the LIC of LED module

The maximum luminous intensity for this sample was 104 cd, the luminous flux was 312 lm, the light output was 155 lm/W, and the emission angle was 150°. The evaluation of the experimental LIC conformity with the calculated ones was estimated by their superimposing them and visual comparison, as well as by a standard deviation determination, which was 3.5 cd (approximately 4 % of the luminous intensity maximum value). In order to determine the temperature distribution over the developed lens surface, the temperature was measured with Testo 881 thermal imager. The maximum temperature on the lens surface is 78.7 °, which does not exceed values typical for similar systems.

4. Conclusion

In modern lighting equipment, the calculation and the modeling of LED module and LD lighting characteristics is an actual task. The developed software package makes it possible to simplify the process of optical LED system design and to improve their quality significantly. In this complex, a LD as a complex product is viewed as a hierarchical structure in the form of parent and child nodes, the geometry of which is modeled with triangulation grids. The computer simulation of LED and its optical system is performed in the form of a free-form lens and a LED module assembly. Its 3D models, the photometric body and light power curves were obtained in two planes. On the basis of 3D-prototyping technology, the experimental samples of LED modules were made and their lighting and thermal characteristics were studied. The results obtained from the measurements show a very good agreement with the calculated ones, which indicate a great potential of such programs. This software package allows studying visually the processes in optical systems without resorting to expensive experiments, which allows recommending it for practical use.

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