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# Concerns Of Design Of The Energy-Efficient Fixtures

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## Abstract

The aspects of the energy efficiency and energy saving in the world and in Russia have been considered. The features of the light devices, light distribution devices have been described, the tasks and possible methods of calculation and design have been analyzed. The mathematic models used in the lighting design and calculations for the lighting fixtures with smooth reflectors have been described. The principles of operation with the software developed for automation of the design process and design of the lighting devices have been described.

**Key words:** energy saving, energy efficiency, automation, program, system, lighting device, reflector, design.

## Introduction

Today energy saving and energy efficiency are the most important and topical issues of the power engineering. One of the main priorities in development of the most countries including Russia is energy saving, increase in the energy efficiency of all branches of industry and agriculture [1, 2]. In order to solve these tasks it is necessary, in particular, to fit all the industry and agricultural facilities with the energy-metering devices, to gradually change over to the energy-saving light sources (LS), in particular, to the LEDs and light devices (LD) on the basis thereof [3-6]. The modern light technologies allow saving up to 40 % of the energy consumed which will globally make about 100 billion euro annually.

Aside from the widespread change to the energy-saving light sources energy-saving may also be implemented due to the optimization of the lighting part of the lighting units (LU), lighting control and regulating systems, rational organization of the lighting use [7]. In order to optimize the lighting part of the LU and lighting mains it is necessary to choose the correct lighting system and light sources, the lights layout and the type thereof according to the light distribution and structure, and in many cases – to design and simulate the optical system of a light device according to the rated light distribution [8].

The software that currently exists at the lighting market does not always meet the requirements of the light devices designers and sometimes they just cannot afford it. This is why the vital task is the development of such models and automated systems for calculation and design of the fixtures that would meet the main demands of the design engineers, will be cheap and affordable [9].

**Main part.**

**1. A light device as a development object**

By design and construction of a LD one should take into account the peculiarities of the lighting devices: production and use of mass proportions, material and labor costs for manufacturing, installation and operation, the LD impact on the technical-and-engineering and aesthetic characteristics of the facilities under construction and reconstruction. The design and construction process exercises the decisive influence on the LDs' usability, their reliability as well as on the production efficiency and operation [10].

First of all, the LD designers try to design fixtures with the maximal light efficiency determined by the light distribution curve, at the same time widening the LD product range according to the various customer needs. The use of computers and automated design systems at all stages of the LD design allows releasing the engineers from performing time-consuming calculations, multi-variant analysis and large volume of graphics works.

**2. Peculiar features of the LD optical systems**

The main role in the redistribution and conversion of the LS light belongs to the optical system of the LD consisting of the elements involved in the light transformation. Among the optical systems of the fixtures the most widely used are the reflecting optical systems – mirror, diffuse and matte ones acting on the basis of the laws of mirror, diffuse and directionally diffused reflection. Depending on the medium and the lighting requirements a reflector shall perform a number of functions, in particular, to diffuse, distribute and direct the light [11]. In the main types of the mirror reflectors the optical properties of the parabolic, elliptic, hyperbolic, cylindrical and flat mirrored surfaces are used.

The fixtures differ by the reflector shapes, generated light intensity curves required (LIC) (a LIC characterizes the fixture light distribution, i. e., dependence of the light intensity value on the direction; the light distribution is usually presented in two planes – transverse and longitudinal) and other (amongst others the aesthetic) reasons. The hybrid systems are also used in the fixtures. Besides, the asymmetric (especially with the linear LS) reflectors are used: parabolic trough, compound hyperbolic, etc.

**3. Mathematical models in the lighting design and design of the mirror-reflector fixtures**

The mirror-reflector fixtures outperform other devices of the same class by their illuminating capabilities, are more multifunctional. They feature the highest efficiency, are quite maintainable. The mirror fixtures allow generating various LIC. The task of lighting design of the LD including fixtures is determination of the geometrical shape of the components of the LD optical system ensuring (upon combined action with the LS selected) the required light distribution [12]. By designing it is necessary to consider the peculiar features of both the lighting materials used for production of the optical system components and the manufacturing processes in terms of the effect by the LD thermal conditions and the environment. In order to calculate the shape of the mirror reflector it is necessary to have an equation that would include the dependence of the radius vector $r$ of a point $M$ on the angles φ and ψ (in the transverse and longitudinal planes) determining the incident ray and the angles α and β (also in the transverse and longitudinal planes) determining the reflected ray (Fig. 1).

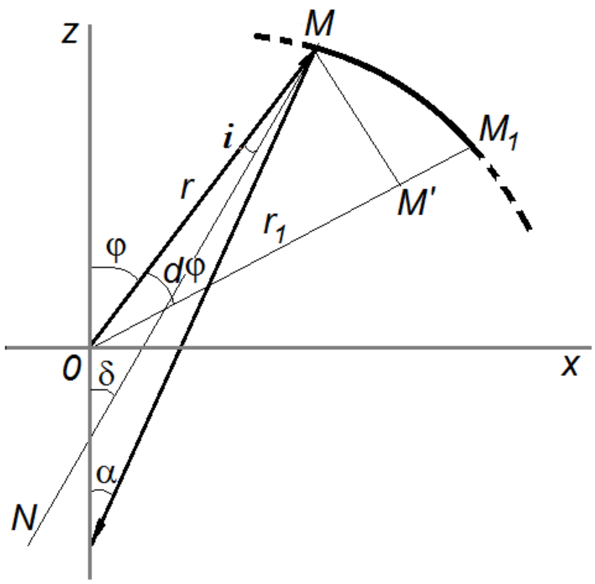



**Fig. 1. The reflector segment with the inclined, reflected and auxiliary rays**

The differential equation of the mirror reflector combines all its main parameters ($r$, φ, ψ, α, β, $p$) [10].

The design of the shape of the mirror circular symmetric reflector is down to the calculation of a single profile curve obtained by variation of the angles α and φ. The differential equation of the reflector profile takes the form

$$\frac{dr}{r} = \mathrm{tg}\, i \cdot d\varphi,$$

Where $i = \dfrac{\varphi - \alpha}{2}$ – the angle of the light incidence at the point $M$ of the reflector (Fig. 1).

In case of a mirrored surface with toroid areas the profile curve consists of the constant curvature ($1/R$) having common normals at the boundary points, i. e, it consists of the segments of the conjugated arcs with the curvature radii $R$ and the curvature center coordinates ($X_Ц$, $Z_Ц$) as functions ($r_i$, $r_{i-1}$, $\varphi_i$, $\varphi_{i-1}$, $\delta_i$, $\delta_{i-1}$):

$$R = \frac{r_{i-1}\cos\varphi_{i-1} - r_i\cos\varphi_i}{\cos\delta_{i-1} - \cos\delta_i},$$

$$X_Ц = X_{i-1} - R\sin\delta_{i-1},$$

$$Z_Ц = Z_i - R\cos\delta_i.$$

Sometimes it is better to form the mirror surfaces by rotating the profile curves with the continuously variable curvature, fitting their parameters depending on the required function $\alpha(\varphi)$. The second-order curves may be used as the profile curves – conics, like ellipse, hyperbole, and parabola. If the surface of the mirror circular symmetric reflector is made from the parabolic segments then such a curve is not smooth, has kinks by passing through which the angle $\alpha$ is changed stepwise. In order to avoid that it is the boundary points of the irregular curve segments shall be connected which results in the introduction of the complementary equations. In this case the profile curve equation takes the following form:

$$r_i = r_{i-1}\frac{1+\cos(\varphi_{i-1} - \alpha_i)}{1+\cos(\varphi_i - \alpha_i)}.$$

The design of the mirror fixtures with the LS in the form of the large luminous elements (fluorescent lamps, mercury arc lamps, etc.) features its own challenges and peculiarities. As a rule, light distribution of a mirror cylindrical fixture is given by the LIC in the profile plane. The profile curve of the cylindrical mirror reflector is calculated by filling it with the second-order curves. The mirror surface for the mirror luminescent fixture shall be only smooth and have parabolic profile. In this case the question about the reflector profile arises that primarily affects the gain factor related to the reflector angle of contact.

The reflector profile is often adjusted to the required LIC experimentally, however, since it depends on a few parameters and the production of reflectors of different shapes and dimensions is rather challenging it makes sense to perform the mathematical modelling of a reflector.

**4. Automated device modeling and design system**

On the basis of the methods of design of the LD there has been developed the software for the automated system performing modeling and design of the lighting devices [12, 13]. This automated system for design and modeling of the lighting devices (hereinafter – system) will allow: designing within a short time the lighting devices of different alternate design and purpose; assessing the efficiency of the LD optical system; specifying the main parameters of an LD optical system and linking them to the LD design in whole with due account for the specifics of its application.

The mathematical aspects of the system include the mathematical models of the LD designed, methods and algorithms of calculations used by the automated design. Here there is a special part representing the specific nature of the design object, the features of its performance and covering the mathematical models, methods and algorithms of generation [4, 12, 13]. The source data for working with the LighTooLux 1.1 program: required light distribution; type of the LS; the number and arrangement of the LS; optical coefficients of the materials of the light-redistributing system; effective beam angle.

The physical appearance of the program is presented in the Fig. 2. Working with the program may be divided into several stages.

At the first stage it is necessary to model the optical system of the LD being designed and choose the LS. To do that use the tabs in the left part of the program desktop window (ref. Fig. 3): *Profile/LIC* (Fig. 3, *a*), *Reflector* (Fig. 3, *b*), *Light sources* (Fig. 3, *c*).

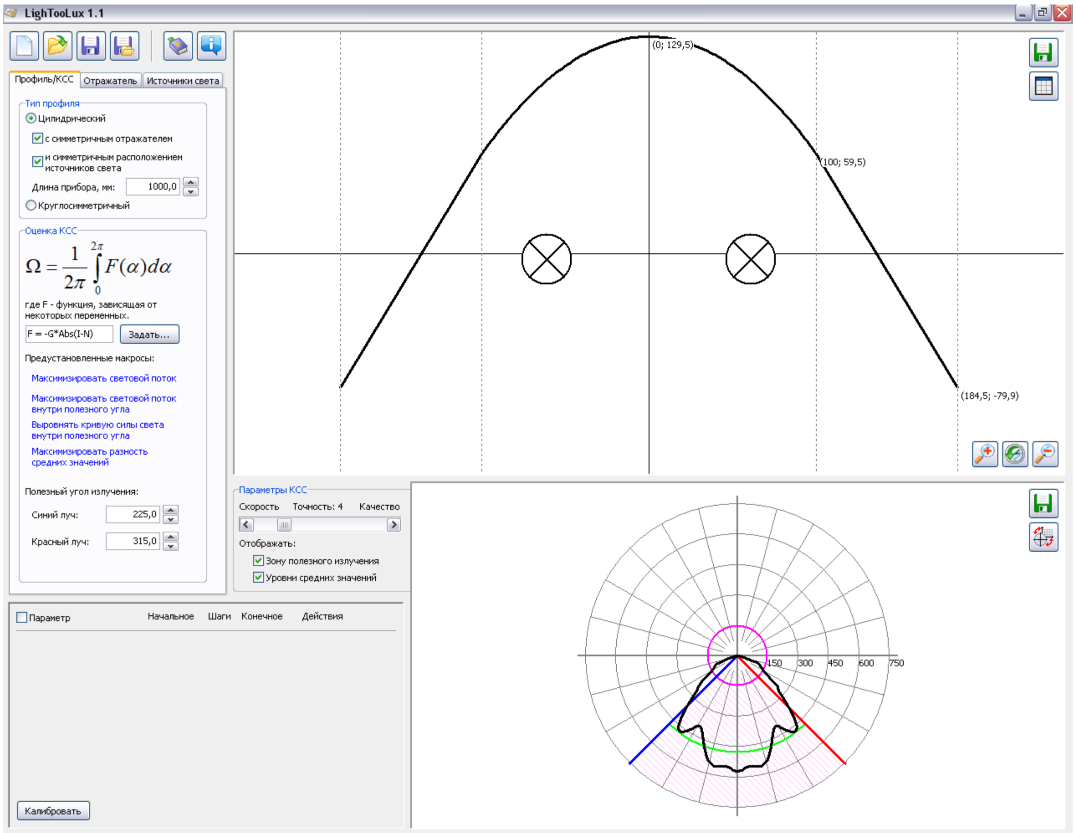
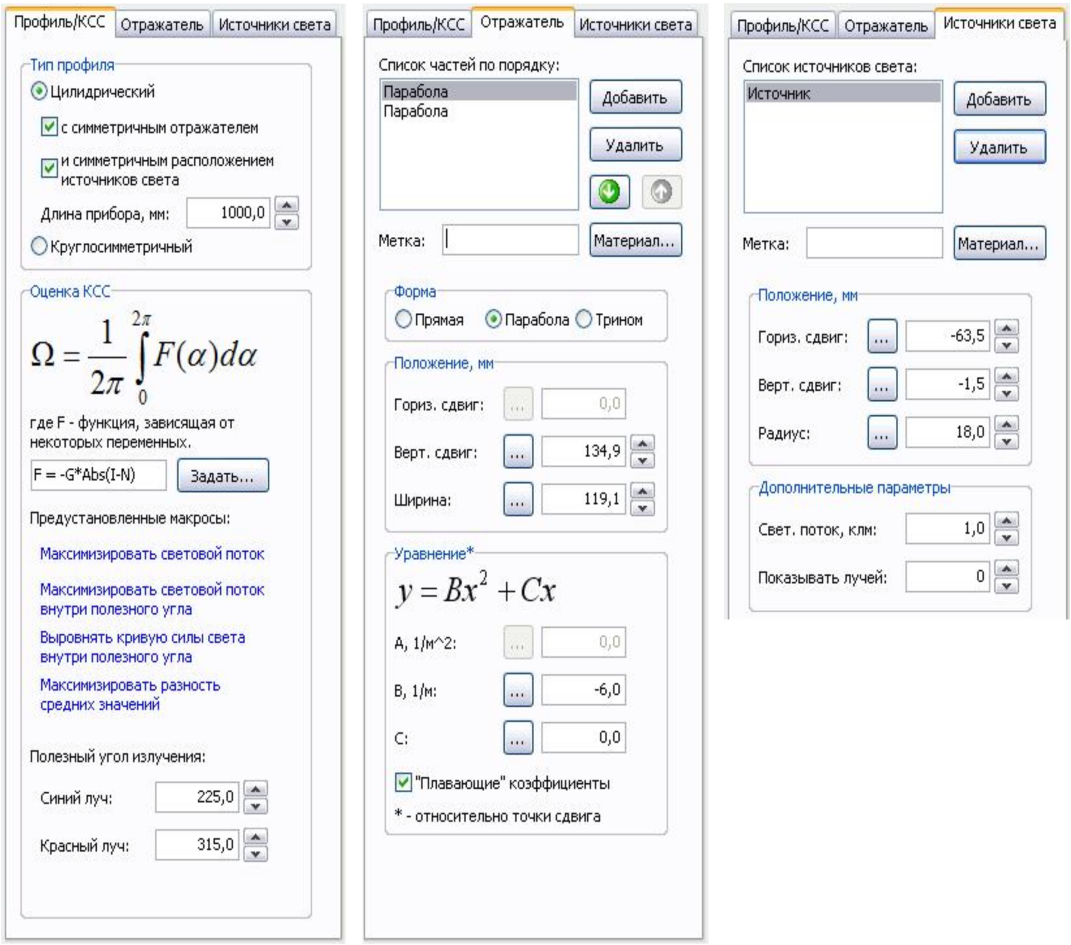



**Fig. 2. Desktop window of the LighTooLux 1.1 program**

The profile type may be cylindrical (being the result of the line motion in parallel to itself along a curve that is perpendicular to the generator) or circular-symmetric the light distribution solid of which features rotational symmetry against the optical axis.

By assignment of the cylindrical profile one may choose the conditions for execution thereof: with symmetric reflector, with symmetric LS layout possible only under presence of the symmetric reflector.




*a)* *b)* *c)*

**Fig. 3. Tabs for selection and assignment of the device parameters: *a* – Profile/LIC; *b* – Reflector; *c* – Light sources**

The program includes the following standard (default) methods of the LIC estimate: maximizing the light flux (the profile with the maximum value of the light flux in all directions is selected); maximizing the light flux within the effective beam angle (the profile with the maximum value of the light flux within the effective angle is selected); adjustment of the LIC within the effective beam angle; maximizing the difference of the average values of the light intensity within the entire solid angle and light intensity within the effective beam angle.

The reflector is made of the autonomous parts that are inextricably connected between each other. One may add the unlimited number of the pats that are intended to be used for the reflector construction. The specifications of the reflector material may be selected with the use of the database “Optical coefficients of the material”.

A reflector with the incident and reflected light rays drawn is presented in the Fig. 4.

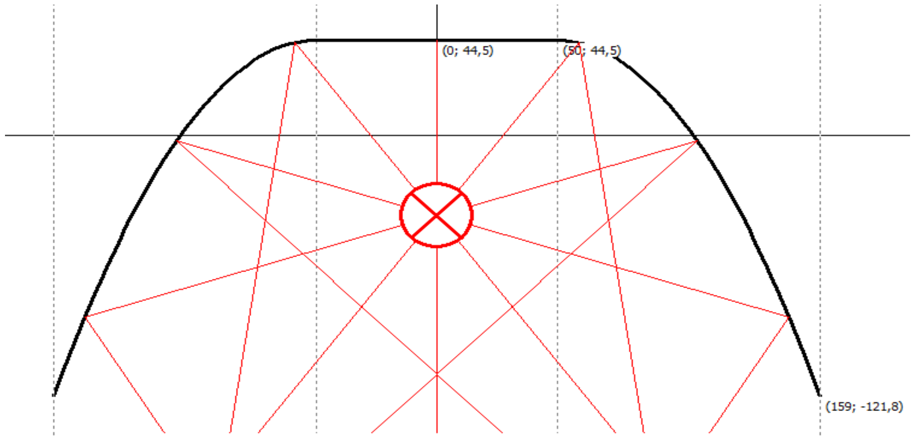



**Fig. 4. Reflector pattern**

In the tab "Light sources" you may select: the number of the LS, radius of the LS bulb, the position with respect to the origin of coordinates, LS light flux, number of the rays sent for visualization of their path, specifications of the bulb material.

At the second stage the clarification, in-depth development of the designed reflector draft under qualitative estimation of the LIC, calibration of the relevant parameters and final LIC construction are performed (Fig. 5). Calibration is the process of selection of the parameters chosen for the maximal estimation of the LIC.

At the third stage the results obtained may be presented for the further data analysis and interpretation in the form of diagrams, schedules and tables.

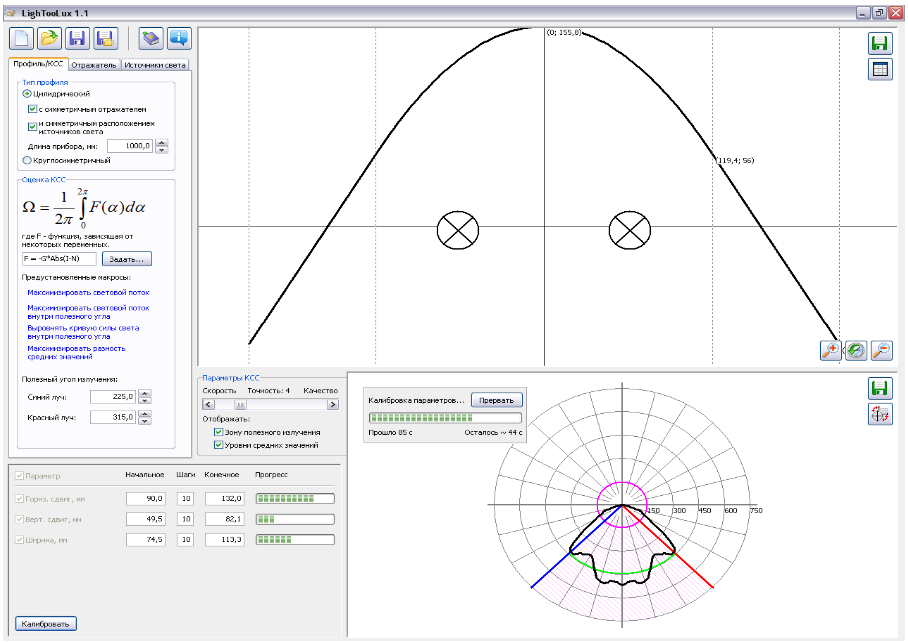


**Fig. 5. Presentation of the process of calibration of the reflector modeled by the geometric parameters**

**Summary**

By the mass production of the LD of different design and purpose it is necessary to automate this task due to the complexity of the design. For this purpose the LighToo-Lux 1.1 program has been developed that allows performing the design and construction of the reflector profile on the basis of information about the LS, reflection coefficient of the reflector material, type of the light intensity curve and other data. At the same time the major task is ensuring the maximum program performance when applied due to the ease of use and maximum visualization of the results obtained.

This software has been patented. The author is ready for cooperation with the Russian and foreign partners.

## Conclusions

The software model designed may be used by analysis, modeling and construction of the modern energy-efficient lighting devices with the maximum saving of the time and physical resources for the development thereof. Design of the LD at the technical proposal stage implemented within the specified system allows the designer solving the task of the LD design automation with the use of the mathematical model of the object, databases necessary for calculations as well as his own experience and intuition.

**Acknowledgement**

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