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TÍTULO: Estudio de las características del sistema óptico reflectivo.

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RESUMEN: En el presente trabajo se consideraron los problemas del cálculo de ingeniería de dispositivos de luz, así como dispositivos ópticos de redistribución de luz, y se describieron las características y las propiedades de las imágenes elementales de un sistema de reflector óptico con un reflector de espejo. La descripción y las dependencias matemáticas para el cálculo de características se presentan utilizando el dispositivo para estudiar los mapeos elementales y las aberraciones.

PALABRAS CLAVES: dispositivo de luz, fuente de luz, sistema óptico, reflector, pantalla elemental.

TITLE: The study of reflective optical system characteristics.

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ABSTRACT: In the present work, the problems of engineering calculation of light devices, as well as optical devices for redistribution of light, were considered, and the characteristics and properties of the elementary images of an optical reflector system with a reflector of light were described. The description and mathematical dependencies for the calculation of characteristics are presented using the device to study elementary mappings and aberrations.

KEY WORDS: light device, light source, optical system, reflector, elementary display.

INTRODUCTION.

The task of a light device (LD) engineering calculation is to determine the geometric shape of LD optical system elements, which provides the required light distribution when combined with a selected light source (LS) (Bayneva, 2015; Bayneva, 2017; Ranjbaran, 2014). The main role of the redistribution and LS light transformation is played by LD optical system, consisting of the elements participating in the transformation of light. The properties and the characteristics of the optical system are the fundamental ones for the design of modern energy-efficient LD (Bayneva & Baynev, 2014; Bayneva, 2017; Saeidi & Prasad, 2014).

DEVELOPMENT.

Features of light device optical systems.

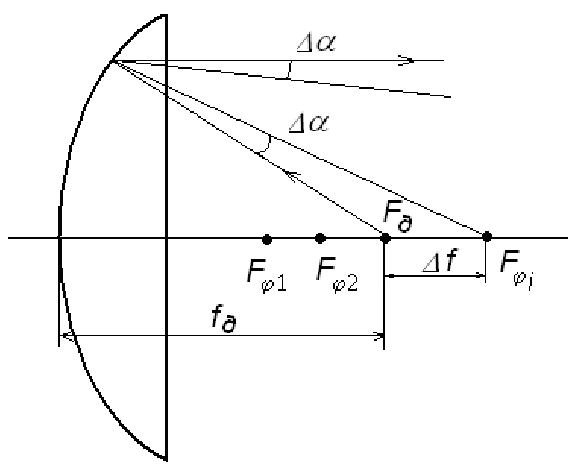
One of the most common optical systems of LD (both luminaires and searchlight devices) is a mirror system. The reflectors of the optical system, as a rule, consist of concave or flat mirror reflectors, can be solid or composite, and their surface can be smooth, wavy, inaccurate, broken, etc. In the main types of mirror reflectors, they use the optical properties of parabolic, elliptic, hyperbolic, cylindrical and planar mirror surfaces (Bayneva, 2017; Borisova et al, 2018).

Paraboloid reflectors are used almost in all types of searchlight devices. Depending on the working conditions and requirements, they can differ significantly in terms of diameter, the angle of coverage, optical accuracy, strength, weight and cost.

Mirror reflectors of projector class devices should be shaped so that their optical system ensures the maximum concentration of a light source flux. This presupposes a definite course of focal falling and reflected light rays (Fig. 1) (Bayneva & Baynev, 2014).

Real reflectors can have deviations from an ideal shape as the result of calculation and (or) technological errors. If light beams parallel to the optical axis fall onto such a reflector, they will not be gathered after the reflection at the point of its theoretical focus F. This will result from the fact that each section of a real reflector has its own focus, i.e. a space point, where the reflected rays, which fell on the zone by a parallel beam, will be gathered. On Fig. 1 F_∂ is the actual focus of a real optical system, f_∂ is the focus distance of a real optical system, Δf is the linear aberration of the light-redistributive device zone of a light device, $\Delta\alpha$ is the angular aberration.

Fig. 1. Characteristics of a searchlight reflective optical system.



Calculation method of ld light part area and brightness.

One of the calculation methods for LD light part area and brightness is based on the principle of source and optical system combination into some sub-set. At that it is assumed that the whole space is saturated with light rays that make up conical beams with the vertices on the points of radiating or irradiated surfaces. A light beam of an optical device (OD) consists of conic beams whose vertices lie on the points of LD radiating surface. The dimensions, the shape and the placement of these beams in space are determined by the size and the shape of the radiating body conical beams and the properties of the optical system itself. Thus, conical ray beams sent to the outer space of a LD contain sufficient information about a radiating body and OD to determine the size and the brightness of its light part. The conical beams of light rays falling from a luminous body to the point of an optical device surface, and the rays sent by an OD to the surrounding space, are called elementary mappings (EM).

The angular dimensions of an EM of a mirror element are determined by the apparent dimensions of a luminous body. If a screen is placed on the path of an EM, then the EM forms a spot on it, called EM track. Its shape and dimensions are determined by the edge axial rays.

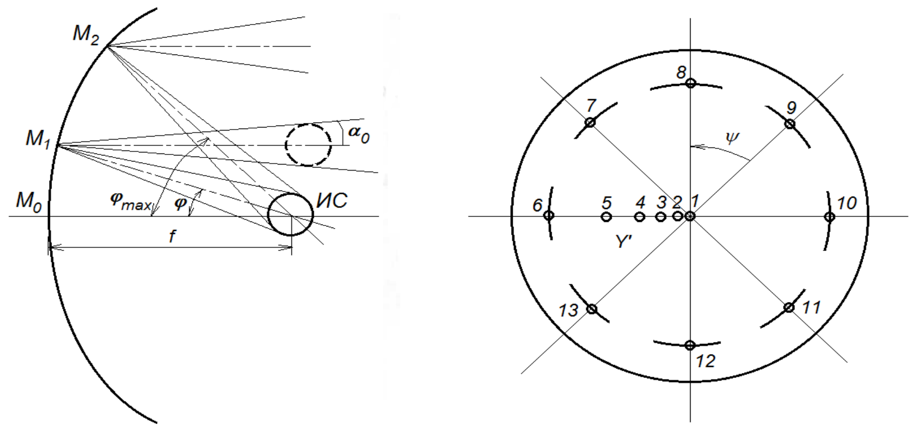
The process of a device light beam development can be considered as the creation of an elementary mapping by each point of the reflector surface, whose axis is parallel to the optical axis of the reflector. Let's describe a paraboloid reflector with a spherical light source placed in the reflector focus (Fig. 2).

The angular dimension of the elementary mapping ξ is determined by the following formula:

$$\xi = \frac{r}{f}\cos^2\frac{\varphi}{2}, \tag{1}$$

where r is the radius of a spherical light source; f - the focal length of a reflector; φ is the angle characterizing the position of the point under consideration on the reflector surface.

Fig. 2. The scheme of the device for EM study: a - the formation of an elementary mapping in a paraboloid reflector; b - the screen with holes.



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Taking the EM on the screen perpendicular to the optical axis (Fig. 2b), we get the outline of a circle whose radius is determined by the angular dimension of the spherical light source and the distance from the screen to the reflector. EM given by the vertex of the reflector M_0 has the largest angular dimension ξ_{max}, then (since $\varphi=0^0$)

$$\xi = \frac{r}{f}. \qquad (2)$$

EM, set by the reflector point M_2, has the smallest angular dimension ξ_{min}:

$$\xi_{min} = \frac{r}{f}\cos^2\frac{\varphi_{max}}{2}, \qquad (3)$$

where φ_{max}– the angle of the reflector coverage.

The shape of EM tracks corresponds to the shape and the location of light sources. With a light source in the form of a thin filament with the length $2l$ and the diameter 2r, located in the focus of the reflector across the optical axis in the horizontal plane, the trace of any EM on a screen perpendicular to an optical axis can be taken as a narrow rectangle located horizontally. In this case, the angular dimensions of EM along the horizontal and vertical lines are determined by the following formulas:

$$\xi_{\varphi\ \textit{ГОР}} = \frac{l}{2f}(1+\cos\varphi)\sqrt{1-\sin^2\varphi\sin^2\psi}, \qquad (4)$$

$$\xi_{\varphi\ \textit{ВЕР}} = \frac{r}{2f}(1+\cos\varphi)\sqrt{1-\sin^2\varphi\cos^2\psi}, \qquad (5)$$

where φ is the angle characterizing the zone position on the reflector; ψ – угол, is the angle characterizing the position of the reflected point on the zone (Fig. 2b).

If the filamentary light source is located in the focus of the reflector along the optical axis, then the trace of any EM on the screen can also be taken as a narrow rectangle. The large side of this rectangle is located in the plane of the meridonal section of the reflector that passes through the reflecting point creating the EM under consideration.

The trace of the EM of the reflector vertex is a circle. For any point of the infinitely narrow circular zone of a reflector, EM will be the same by shape and size, but with different directions of the axes in space. The angular dimensions of EM of any reflecting point in this case for the maximum and minimum angular size of EM are defined as follows:

$$\xi_{\varphi\max} = \frac{l}{2f}(1+\cos\varphi)\sin\varphi, \qquad (6)$$

$$\xi_{\varphi\min} = \frac{r}{2f}(1+\cos\varphi), \qquad (7)$$

Let's take the derivative of $\xi_{\varphi\max}$ along dφ and equate it to zero:

$$\frac{\xi_{\varphi\max}}{d\varphi} = \frac{l}{2f}\left[-\sin\varphi\sin\varphi + (1+\cos\varphi)\cos\varphi\right] =$$

$$= \frac{l}{2f}\left(-\sin^2\varphi + \cos^2\varphi + \cos\varphi\right) = \frac{l}{2f}(\cos 2\varphi + \cos\varphi) = 0. \qquad (8)$$

This condition is satisfied at $\varphi = 60°$. As was noted above, paraboloidal reflectors have deviations from a given shape at various points of the surface, which is conditioned by the assumptions made during the reflector shape calculation, or by insufficiently precise surface treatment, which leads to aberration. With an aberration paraboloid reflector, the axes of elementary mappings will not be parallel to the optical axis of the reflector, but will make the angles $\Delta\alpha$ with it, which are the angular dimensions of the longitudinal aberration Δf. The shape and the dimensions of EM will remain the same as in the case of a non-aberrational reflector. For this zone, the value of $\Delta\alpha$ can be found from the following relation:

$$\Delta\alpha = \frac{\Delta f}{2f}(1 + \cos\varphi)\sin\varphi. \qquad (9)$$

Device for the study of elementary mappings and aberration.

The measurement of the angular aberration of the zone can be explained by Fig. 3. The center of the ball LS is integrated with the real focus of the aberrational paraboloidal reflector.

If the reflector zone was aberrant, the EM axis of the point M of the zone would be parallel to the optical axis of the reflector and would be at the distance Y from the reflector. With the aberration zone, the EM axis of the point M makes the angle $\Delta\alpha$ with the optical axis of the reflector and crosses the screen at the distance Y from the optical axis of the reflector. The size of the angular zone can be calculated from the following formula:

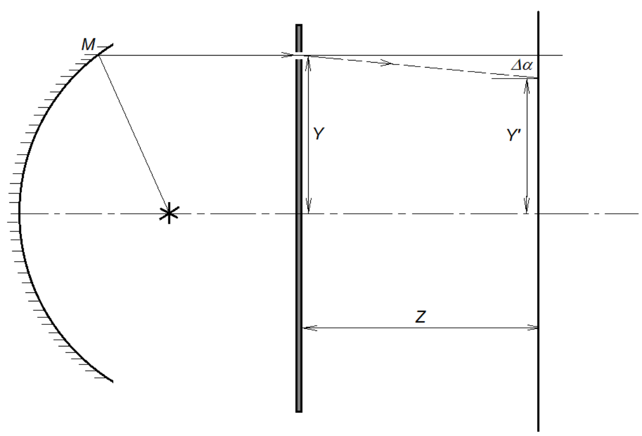
$$\Delta\alpha = arctg\frac{Y' - Y}{Z} = arctg\frac{\Delta Y}{Z}, \qquad (10)$$

where Y'– is the distance on the screen from the center of the elementary mapping to the optical axis of the reflector; Y is the distance from the examined point of the reflector to the optical axis (the distance from the hole, corresponding to the examined point of the reflector in the metal disc, to the central hole in the disk, and Z is the distance from the reflector to the screen (Figure 3).

The device consists of a light device model with a reflective optical system, with the following parameters of a glass reflector: diameter D = 250 mm; the angle of reflector coverage $2\varphi_{max} = 120°$; focal length $f = 108$ mm. The light hole of the LD model is covered by a metal disk with holes (Fig. 2b). The holes on the disc are located in one radial direction and in one circular zone. Separate holes on the metal screen pass the elementary displays created by small-sized corresponding parts of the reflector.

The linear dimensions and the shape of EM tracks correspond to the shape, location and the size of an applied light source, the position of the reflecting area on the reflector surface, the distance from the screen to the reflector. Opening the holes on a metal disk in succession, you can explore the EM created by different reflector points.

Fig. 3. To the calculation of angular aberration.



The study of EM and the aberration of the optical system on the above-described device is recommended in the following sequence:

1. To place the screen at a certain distance Z from the disk with holes. Install the glow body perpendicular to the optical axis of the reflector. Opening the holes on the metal disk successively, measure the linear dimensions of elementary mapping traces on the screen (horizontally l' and vertically h').

2. According to the data of measurements, calculate the actual angular dimensions of EM.

3. Install the glow body along the optical axis. Opening the holes in the metal disk sequentially, measure the linear dimensions of EM tracks on the screen (the maximum size l' and the minimum size h').

4. By placing the glow body along the optical axis, to determine the value of the angular aberration according to the formula (10) for the reflector points corresponding to the radial holes in the metal disk.

5. To determine the focal length of each radial point of the reflector:

$$f_{\varphi} = f + \Delta f . \qquad (11)$$

CONCLUSIONS.

The described device for the experimental study and the measurement of elementary mappings and aberration characteristics of a reflecting optical system of a light device allows to determine the properties and the characteristics of an optical system quickly and easily and to use the obtained data for the analysis and the optimization of LD projected optical system.

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