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Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

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PHYSICS

L. A. VASIL' EV, E. P. KAZANDZHAN, V. S. SUKHORUKIKH

DIFFRACTION THEORY OF SHADOW PHOTOMETRIC KNIFE-EDGE AND SLIT METHODS

(Presented by Academician I. V. Obreimov, 18 IX 1968)

The measurements carried out by shadow photometric methods are based on a linear dependence between the angle of deflection of a ray and the illumination of the image plane of the shadow instrument ([1]). This dependence follows from the geometrical scheme of the methods: the illumination is assumed to be proportional to the area of the undiaphragmed part of the image of the light source.

Fig. 1

The actual distribution of illumination follows the linear dependence only to one degree or another. Therefore, in measurements there arises a systematic error caused by neglect of diffraction phenomena.

The authors have considered the diffraction theory of the shadow photometric knife-edge and slit methods. The distribution of illumination in the diffraction pattern has been found, and the dependence between the diffraction error and the measurement conditions has been established.

The usual measuring scheme is considered (Fig. 1). It includes a collimator O_k with a slit light source S and the receiving part of the shadow instrument with a Foucault knife H in the second focal plane of the optical system O_p. The surface of the light wave is assumed to be a paraboloid or a parabolic cylinder. The planes of symmetry of the wave are parallel to the coordinate planes xOz and yOz. In the object plane the wave is bounded by an opaque screen—the half-plane R.

To find the illumination of the image plane, the Huygens–Fresnel principle ([2]) is applied twice: first in determining the amplitude of the light in the second focal

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Fig. 2

Figure 2: Fig. 2

Fig. 3

Figure 3: Fig. 3

plane of the system O_p, and then in the image plane $x'O'y'$. The illumination is

$$I_{\pm}(a,b) = \frac{1}{2\pi^2}\int_{-1}^{+1}\left|\int_{\eta a+\eta t-\eta\omega}^{\eta a+\eta t}\int_{-\infty}^{b\pm z}\exp[i(z^2-y^2)]\,dz\,dy\right|^2 dt, \qquad (1)$$

where

$$a = \frac{m}{f'}\frac{1}{\alpha};$$

m is the distance from the middle of the elementary image of the slit SA', corresponding to the point A under consideration, to the edge of the Foucault knife; f' is the second focal distance of the optical system O_{p}; 2α is the angular size of the slit light source in the direction perpendicular to the edge of the Foucault knife;

Fig. 2

Fig. 3

$$b = \frac{h}{|\cos(\varphi-\psi)|}\sqrt{\frac{\pi|K|}{\lambda}};$$

h is the distance from the image A' of the point A under consideration to the image of the edge of the opaque ···

screen; ψ, φ are the angles of the slit and the screen with the plane of symmetry of the wave surface; λ is the wavelength of the light; K is the curvature of the section of the wave surface by a plane perpendicular to the edge of the Foucault knife; $\eta = a\sqrt{\pi/\lambda|K|}$; $\omega = \frac{L}{f}\frac{1}{a}$; L is the distance from the edge of the Foucault knife to the edge of the limiting diaphragm, parallel to it, in the second focal plane.

There are two types of illumination distribution (the signs $+$ and $-$ in the upper limit of the inner integral). They correspond to diffraction patterns that can be made congruent with the diffraction patterns for a spherical wave, when the

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Fig. 4

Figure 4: Fig. 4

edge of the light interval between the shadow from the knife and the image of the screen forms an acute (+) or obtuse (−) angle.

For measurements, only the penumbra region is of interest ($-1 \leq a \leq 1$), where the illumination, according to geometrical optics, is equal to $I_{\mathrm{r}}(a) = (1 + a)/2$.

In the interval of variation of the quantity b, $(0, \infty)$, three cases are considered. For $b \gg 1$, for the right-hand side of (1) an approximate expression has been obtained, the more accurate the larger b is. The deviation of the illumination distribution from a linear one may be judged from the curves in Fig. 2, corresponding to the limiting case ($b = \infty$), when there are no limiting diaphragms in the object plane.

Fig. 4

For $b > 1$, the right-hand side of (1) is represented as the sum of the illumination for an unlimited wave and a term taking into account diffraction from the screen in the object plane. The maximum diffraction error in measuring the deflection angle of a light ray is

$$\varkappa = \left|\frac{\cos\left[b^2 + 2b\eta(a+1)\right]}{2\pi b\left[b + \eta(a+1)\right]}\right| + \left|\frac{dK/da}{2\pi\eta^2 K(a^2-1)}\right| + \left|\frac{dK/da}{4\pi\eta K\left[b + \eta(a+1)\right]}\right|. \quad (2)$$

The first term in (2) is the error occurring in the measurement of the angle of rotation of a plane wave; the second, that of an unlimited wave with curvature varying in the course of the experiment.

For $0 \leq b \leq 1$, expression (1) has been transformed into a form acceptable for computation on an electronic digital computer; in doing so, representations of the Fresnel integrals by power and asymptotic series were used. Figs. 4 and 3 give examples of calculations of the quantity $\Delta I_{+}(a, b) = I_{+}(a, b) - I_{\mathrm{r}}(a)$.

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