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FRESNEL DIFFRACTION BY A ROUND APERTURE

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By using a gas-laser light source it is possible not only to observe Fresnel diffraction visually, but also to study experimentally, as part of a laboratory course, the distribution of the illumination along the axis of a round aperture, which illustrates clearly the application of the Fresnel-zone method for the study of diffraction problems.[1, 2]

The main conclusion of the theory is as follows: The illumination along the axis is an oscillating function of the distance from the aperture, and is determined by the number of open Fresnel zones of the wave front. If a plane monochromatic wave is incident on an aperture of radius ρ, then the extremal values of the illumination occur at distances r, from the aperture, satisfying the condition

$$\rho^2 = k\lambda r, \tag{1}$$

where λ is the wavelength and k = 1, 2, 3, ... is the number of open Fresnel zones.

The experimental setup is shown in Fig. 1. A beam of light from an He-Ne laser 1 is collimated by the telescope tube 2. A diaphragm 3 with a round aperture is mounted on the exit end of the tube.

Prior broadening of the beam by the tube makes it possible to illuminate the aperture uniformly by the central section of the wave front. The diffraction picture has in this case an axial symmetry and is most clearly pronounced. The lens 4 produces on the screen 5 a magnified image of the diffraction picture produced in the plane A conjugate to the lens. At a short distance between the aperture and the screen, on the order of 1.5–2.0 m, one can see the central diffraction spot, surrounded by several alternating dark and light rings, in a darkened room, in transmitted or reflected light, using a ground-glass screen. When the lens is moved along the axis of the aperture, the maxima and minima of the illumination exchange places. The diffraction picture is large enough, with the apparatus parameters indicated above, to be demonstrated in a lecture room. The brightness and contrast of the picture make it possible, as shown by experiment, to demonstrate this phenomenon by television.

For quantitative measurements, the opaque screen 5 is fastened directly on the end surface of a photomultiplier 6. A small opening in the screen transmits the center of the magnified image of the central diffraction spot and serves as a field diaphragm. The lens is rigidly coupled to the photomultiplier, and when the two are moved together during the course of the measurements the distance a_2 between the lens and the photocathode remains unchanged. The distance a_1 from the lens to the plane A is determined uniquely by the distance a_2 and by the focal length of the employed lens, and therefore the magnification a_2/a_1 of the diffraction picture is the same for any plane A.

All the elements of the apparatus are mounted on an optical bench. During the course of the measurements one determines the photocurrent and the distance R from the lens to the diaphragm needed to determine the distance r from the diaphragm to the investigated plane A ($r = R - a_1$). The accuracy with which the aperture in the screen is aligned with the center of the diffraction-picture image is monitored by means of slight transverse displacements of the stage on which the photomultiplier is mounted. During this displacement, the photocurrent passes through its extremal value, which corresponds exactly to precise alignment.

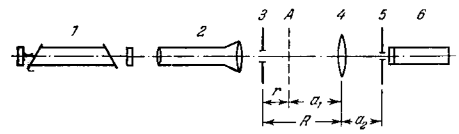

FIG. 1. Diagram of experimental setup.

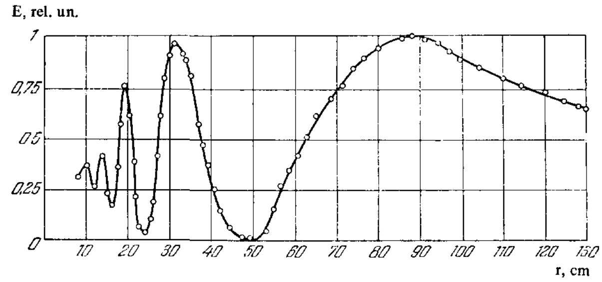

FIG. 2. Distribution of illumination along the axis of a round aperture.

Figure 2 shows by way of an example the results of the measurement of the illumination along the axis of an aperture of 1.5 mm diameter, with the following apparatus parameters: laser radiation power 1 mW, wavelength λ = 6328 Å, telescope tube magnification 8×, focal length of lens f = 60 mm, distance a_2 = 360 mm. The diagram shows the region of the Fresnel diffraction and the start of the region of the Fraunhoffer diffraction ($k < 1$). The positions of the maxima and minima of the illumination coincide well with the values calculated in accord with the formula (1).* In accordance

*By using Sommerfeld's method [1] it is possible to find the distribution function of the illumination along the axis of a round aperture. If a plane wave is incident on the aperture, then for $r \gg \rho$ we have

$$E = 4E_0 \sin^2 \pi\rho^2/2\lambda r, \tag{2}$$

where E_0 is the illumination produced on the aperture by the incident wave. The extrema (2) correspond to the condition (1), and all maxima have the same magnitude and all minima are equal to zero. With decreasing r, the maxima of the curve become denser. An appreciable deviation of the experimental curve from the theoretical one occurs at such values of r at which the resolving power of the employed lens in the direction of the optical axis [3] turns out to be insufficient for a distinct separation of the extrema.

with the theory, the illumination at a point on the axis, for which one Fresnel zone is open, is four times larger than the illumination in the points close to the aperture, for which the wave front can be regarded as completely open.

[1] A. Sommerfeld, Optics, Academic, 1954.
[2] R. W. Ditchburn, Light, Wiley, 1963.
[3] K. Michel, Fundamentals of Microscope Theory (Russ. transl.), Gostekhizdat, 1954.

Translated by J. G. Adashko