FRAUNHOFER and FRESNEL DIFFRACTION (1 Lab Period)

Objective   Observe and analyze far-field (Fraunhofer) and near-field (Fresnel) diffraction for a variety of apertures.

References   Hecht, Chapter 10, especially 10.1 (all); 10.2 (subsections 10.2.1 and 10.2.5); and 10.3 (subsections 10.3.1, 10.3.2 and 10.3.3)

Overview

Fraunhoffer Diffraction: Consider an aperture (single slit) of width b, illuminated by plane waves (i.e. from a source infinitely far away) of wavelength λ. An observation screen is placed in the far-field, at a distance r from the aperture. In the *Fraunhoffer limit* (i.e. for $r \gg b^2/4\lambda$) a diffraction pattern is observed, whose intensity minima are described by

$$m\lambda = b\ sin\theta_m \qquad\qquad\qquad (5.1)$$
$$m = \pm 1, \pm 2, \pm 3, \ldots \text{ (for dark fringes)}$$

where θ_m is the angular position of the mth minimum, with respect to the incident wave vector, as measured from the center of the slit. As long as the observation screen remains in the far-field, the center of the diffraction pattern will always be an intensity maximum, regardless of distance from the slit.

Fresnel Diffraction: Now consider a circular aperture of radius R, illuminated by a point source at a finite distance ρ, and an observation screen in the near-field (i.e. at a distance $r < R^2/\lambda$ from the aperture). Fresnel diffraction is observed, and the intensity of the center of the diffraction pattern will not necessarily be a maximum, but will depend on the distance from the aperture. In particular, as the distance r is varied (in the near field) along a line perpendicular to the plane of the aperture, the intensity of the center of the diffraction pattern will alternate between maximum and minimum, according to the following approximation:

$$m = (\rho+r)R^2\ /\rho r\lambda \qquad\qquad\qquad (5.2)$$
$$m = \text{odd (intensity maxima)}$$
$$m = \text{even (intensity minima)}$$

The integers, m, in Eq. 5.2 represent the number of *Fresnel zones* contained within the aperture, as perceived from the observation screen. If the aperture contains a single zone or any odd number of zones, the center of the near field will be bright. If the aperture contains two zones or any even number of zones, they tend to cancel out in pairs, and the center of the near field will be dark.

If the source of illumination is sufficiently far away ($\rho\rightarrow\infty$), Eq. 5.2 can be approximated by

$$m = R^2\ /r\lambda \qquad\qquad\qquad (5.3)$$
$$m = \text{odd (intensity maxima)}$$
$$m = \text{even (intensity minima)}$$

Equipment:
- Helium-neon laser with beam expander
- Diffraction plate with single-, double- and multiple slits
- Diffraction aperture plate with various circular apertures
- Optical rail and riders
- Image board

LAB SAFETY:
Do not look into the laser beam. Eye injury and blindness may result.

Procedure:

A. Fraunhofer Diffraction

With a point source and without lenses, we can satisfy the conditions for Fraunhofer diffraction by a particular object only if it is a sufficiently large distance from both the source and the observing screen. For a single slit of width b, the Fraunhofer condition without lenses requires both ρ and $r >> b^2/4\lambda$, where ρ and r are the distances of the source and the observing screen, respectively, from the diffracting object.

(1) Choose one of the single slits in the diffraction plate, whose width is no more than a few tenths of a millimeter. Estimate the value of r that will satisfy the Fraunhofer condition when the slit is illuminated by parallel light from a HeNe laser (*i.e.*, $\rho \rightarrow \infty$ for the incident plane wave).

(2) For this value of r, calculate the expected separation between the minima on either side of the central maximum in the diffraction pattern.

Your answer to (2) may seem rather small for convenient measurement. One way to spread out the diffraction pattern would be to use an arrangement of lenses. An easier method is just to increase r using the entire length of the lab bench and/or using plane mirrors.

(3) Using a single slit, obtain a satisfactory Fraunhofer diffraction pattern. Display it on a sheet of white paper and mark the locations of the intensity minima. Plot your data in a way which will enable you to determine the width of the slit (Eq. 5.1).

(4) Measure the width of the slit directly, using a travelling microscope, and compare the measured width to the value obtained from your plot of the data.

B. Fresnel Diffraction

(1) In this section you will observe near-field (Fresnel) diffraction. In order to compare your observations with predictions, it may not be adequate to approximate the laser as a parallel beam (source at infinity). Before you begin your observations, you should estimate a value for ρ, the apparent distance from source to aperture, for a diverging laser beam (as in Hecht, Fig. 10.38). This can be done by measuring the diameter of the laser beam at several distances along the full length of the lab bench, in order to determine the beam divergence. Assume that the wave-front

illuminating the aperture is a portion of a spherical wave emanating from a point source. (This assumption is indeed a correct one, and the laser beam is an example of a *Gaussian* wave).

(2) Study the Fresnel diffraction patterns created by a circular aperture at various distances (in the near-field) from the aperture. In particular, observe the on-axis intensity as a function of distance, r, from the aperture. Record the distances, r, at which you observe the maxima and the minima in the on-axis intensity. Make a few sketches in your notebook of the diffraction pattern produced at several different distances, and label your sketches clearly with the distance at which the pattern was observed.

(4) Compare your observations with theoretical expectations. Do your observations agree better with the predictions of Eq. 5.2 (source at a finite distance) or Eq. 5.3 (source infinitely far away)?