Experiment Nr. 44+45

Michelson Interferometer:
Determination of the laser light wavelength and the refractive index of air

Theory

The Michelson Interferometer is the fundamental form of a large variety of two-beam interferometer configurations. Light from the source L (Fig. 1), incident on a semi-reflecting plane-parallel plate d_1, is divided into two beams u_1 and u_2 of equal amplitude, the axes of which fall normally on the mirrors Z_1 and Z_2. The returned beams re-unite at the semi-reflecting surface of d_1. The interference pattern can be viewed directly by eye or by means of camera view D. Note that the light reflected by Z_2 passes through the plate d_1 three times while that from Z_1 had only a single passage. The compensating plate d_2 is identical in thickness to d_1 and is set accurately parallel to d_1.
Its insertion then equalizes the glass paths in the two beams. When the mirrors Z_1 and Z_2 are perpendicular, and Z_1 is slightly closer than Z_2 the image of Z_1 will fall in front of Z_2, at a position Z_1 and a series of interference rings will be seen. When the mirrors are equidistant and perpendicular, the interference field will be uniform (dark or bright). When the surfaces Z_2 and Z_1 are not precisely parallel and their distance apart is very small, a series of fringes approximating to straight lines will be seen. For a non-laser source, fringe contrast increases as the distance apart is reduced. Among the interesting demonstrations that can be performed using the unit in the form of a Michelson Interferometer are:

- Formation of circular, localised monochromatic and white light fringes.
- Establishment of zero path differences.
- Accurate comparison of wavelengths.
- Measurement of refractive indices of gases and transparent solids.
- Accurate determination of inhomogeneities and surface variations of transparent solids.
- Accurate measurement of small changes in length.

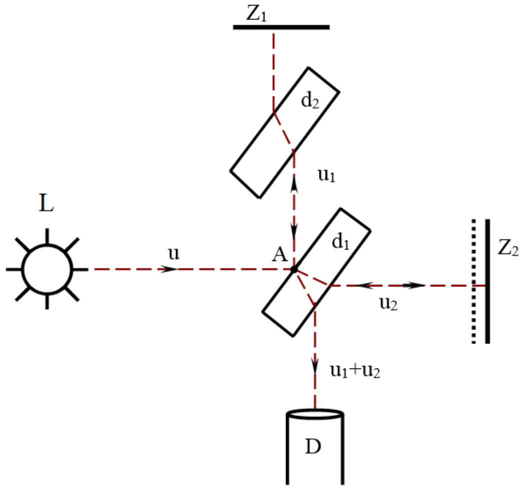

Fig. 1 Schematic view of Michelson Interferometer

The mirror Z_2 is moved indirectly by means of a micrometer screw. It is necessary to find the proportionality factor p between the screw and mirror movements given by

$$p = \frac{\Delta Z}{\Delta l}$$

where Δl is the displacement of the micrometer screw and ΔZ the corresponding displacement of the mirror. This is done using a He-Ne laser giving monochromatic light of wavelength 632.8 nm.

Measurement objectives

1. Determine the wavelength of the He-Ne laser source using Michelson interferometer. Compare the resulting value to the tabular data.

2. Determine the refractive index of air. Compare the result to the tabular data.

Comments

Ad 1. The position of the interference maximum (bright fringes distance) is given by following formula:

$$\Delta x = n\lambda,$$

where Δx is the path difference of the u_1 and u_2 beams and λ is the light source wavelength. If the mirror Z_2 is moved by the distance of ΔZ, the beam path u_2 will change by $2\Delta Z$. By this movement, a certain number of fringes k will pass the central position of the camera field view. Thus, the change of the beam path could be defined as

$$2\Delta Z = k\lambda$$

and the light source wavelength is

$$\lambda = \frac{2\Delta Z}{k}$$

Consider that the proportionality factor p = (10.044±0.022). The light source wavelength could be calculated as

$$\lambda = \frac{2\Delta l}{kp}$$

For better measurement accuracy, determine the $\frac{\Delta l}{p}$ proportionality as a linear function. Carry out at least 10 measurements of Δl and select the number of counted fringes p = 20.

Ad 2. In this measurement, the positions of the mirrors Z_1 and Z_2 will be fixed. Place the measurement cuvette in the beam path of a Michelson interferometer and evacuate it. Determine the linear proportionality between the number of fringes passed in the camera field against the cuvette pressure. The beam path change Δd within the cuvette could be determined as

$$\Delta d = l\Delta n$$

where l is the cuvette length and Δn is the change of the refractive index caused by the change of the pressure in the cuvette. If the refractive index of air at the standard atmospheric pressure is n_{p} and the refractive index of vacuum (fully evacuated cuvette) is n_0, then

$$\Delta d = l(n_{\mathrm{p}} - n_0) = l(n_{\mathrm{p}} - 1)$$

and the refractive index of air is

$$n_p = 1 + \frac{\Delta d}{l}$$

The light beam passes twice the internal cuvette space. Thus, the total optical beam path Δd should be considered to be

$$k\lambda = 2\Delta d$$

and the refractive index is then

$$n_p = 1 + \frac{k\lambda}{2l}$$

Consider that the change of the air refractive index is directly proportional to the change of the air pressure. Thus, the refractive index of air changes with pressure as follows:

$$n_p = 1 + Kp$$

where K is the proportionality factor and p is the air pressure. Therefore, the linear equation term can be defined as

$$\frac{k\lambda}{2l} = Kp \qquad \rightarrow \qquad k = \frac{2lK}{\lambda}p$$

Use the hand vacuum pump to evacuate the cuvette space and count the shifted interference fringes in the camera field. The linear trend of the obtained data is $k = f(p) = ap$. The angular coefficient a corresponds to the proportionality factor K:

$$a = \frac{2lK}{\lambda}$$

Finally, if the angular coefficient a was determined, the air refractive index will be calculated as

$$n_p = 1 + \frac{\lambda a}{2l}p$$

If the refractive index of air n_p at the standard atmospheric pressure p_0 should be evaluated thus the last formula will be modified to

$$n_p = 1 + \frac{\lambda a}{2l}p_0$$