3.3 Constructing a Michelson Interferometer and Measuring the Refractive Index of Air

Objective:

Learn how to assemble a Michelson interferometer, and measure the refractive index of air

Experimental Setup

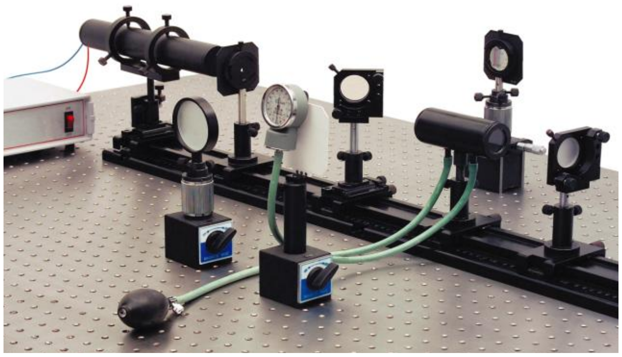

Figure 3-1 Photo of experimental setup

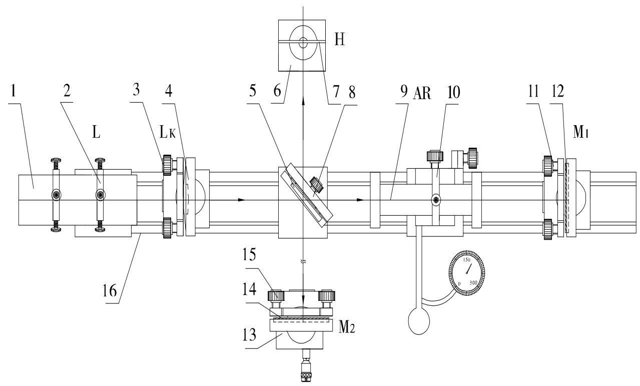

Figure 3-2 Configuration of system

Note: Photos may vary from actual parts

1: He-Ne Laser L (LLL-2)
2: Laser Holder (SZ-42)
3: Lens Holder (SZ-08)
4: Beam Expander Lens L_1 (f'=4.5 mm)
5: Beam Splitter *BS* (5:5)
6: Magnetic Base (SZ-04)
7: White Screen *H* (SZ-13)
8: Plate Holder A (SZ-12)
9: Air Chamber with Pump *AR*
10: Aperture Adjustable Clamp (SZ-19)
11: Two-axis Tilt Holder (SZ-07)
12: Flat Mirror M_1
13: Magnetic Base (SZ-04)
14: Flat Mirror M_2
15: Two-axis Tilt Holder (SZ-07)
16: Optical Rail (LEPO-54)

Principle

Figure 3-3 shows the schematic of a Michelson interferometer, in which a light ray from source *S* strikes a beam-splitter *BS* that reflects 50% of the incident light and transmits the other 50%. The incident beam is therefore split into two beams; one beam is reflected toward mirror M_1, the other is transmitted toward mirror M_2. The light reflected from M_1 transmits through the beam-splitter to the observer's eye *E*, and the other light reflected from M_2 is reflected by the beam-splitter *BS* to the observer's eye *E*.

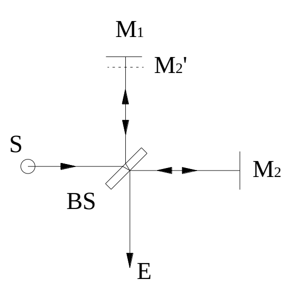

Figure 3-3 Schematic of Michelson interferometer

Since the beams are from the same light source, their phases are highly correlated. When a lens is placed between light source and beam-splitter, the light ray spreads out, and an interference pattern of dark and bright rings, or fringes, can be seen by the observer. There are numerous variants of the Michelson interferometer with different features. Two important examples are the Mach-Zehnder and the Sagnac interferometer.

If we place an air chamber in the light path between beam splitter and mirror M_2, and then change the density of the air (by deflating or pumping the air), the length of the light path will change by δ

$$\delta = 2\Delta n l = N\lambda , \quad \text{so } \Delta n = N\lambda / 2l \tag{3-1}$$

where l is length of the air chamber λ is the wavelength of the light source, N is the number of the fringes counted, and n is the refractive index of air. The refractive index of air n is dependent upon both temperature and pressure. If n is near unity, then n-1 is directly proportional to the density of the gas, ρ. For ideal gas:

$$\frac{\rho}{\rho_0} = \frac{n-1}{n_0 - 1} \tag{3-2}$$

Therefore,

$$\frac{\rho}{\rho_0} = \frac{PT_0}{P_0 T} \tag{3-3}$$

where T is the absolute temperature, P is the ambient pressure. So we get

$$\frac{PT_0}{P_0 T} = \frac{n-1}{n_0 - 1} \tag{3-4}$$

When temperature is constant, then

$$\Delta n = \frac{(n_0 - 1)}{P_0} \Delta P \tag{3-5}$$

Based on equation (3-1), $\Delta n = N\lambda / 2l$, we have

$$\frac{(n_0 - 1)}{P_0} \Delta P = N\lambda / 2l \tag{3-6}$$

So

$$n_0 = 1 + \frac{N\lambda}{2l} \times \frac{P_0}{\Delta P} \tag{3-7}$$

where P_0 is the atmospheric pressure (P_0= 101.325 kPa); l=200 mm.

Experimental Procedures:

1. Refer to Figure 3-2, align all components in same height on the rail;
2. Adjust the output of the He-Ne laser to make it parallel along the optical rail (beam expander lens should not be inserted at this moment);
3. Put in beam splitter *BS* at an angle of 45° with respect to beam axis, and adjust its tilt to make the two beams (transmission and reflection) parallel to the table;
4. Adjust the tilt of mirrors M_1 and M_2 to make the reflected beams coincide with their incident paths, and the two beam spots on the screen *H* overlap together;
5. Insert beam expander L_1, finely adjust beam splitter, M_1 and M_2, till concentric interference rings can be observed on the screen *H*;
6. Insert an air chamber between beam splitter and M_1, adjust the chamber parallel to optical path, pump air into the air chamber till the maximum permit pressure is reached (40 kPa) and write as ΔP;
7. Slowly release the air valve, count the number of interference rings changed in the center till air pressure falls to zero (using the provided hand tally counter);
8. Repeat steps 6 and 7 several times to obtain averaged data;

Calculate the refractive index of air according to equation (3-7).