Lab 13 - Michelson Interferometer

I. Objective

To study the principle of interferometry and its application to relative displacement measurement.

II. Introduction

Interference deals with the superposition of coplanar electric field of light. Broadly speaking, interference may be produced by the division of wavefront or amplitude. An important device representing the latter is the Michelson interferometer which was used in the famous Michelson- Morley experiment to detect the presence of ``ether". The interference of two beams produces a series of dark and bright images known as the fringes. In order for the fringes to appear, it is necessary to use a monochromatic (or nearly so) extended source. For example, a He-Ne laser is one such source. A standard Michelson interferometer set-up is shown in Figure 1 below:

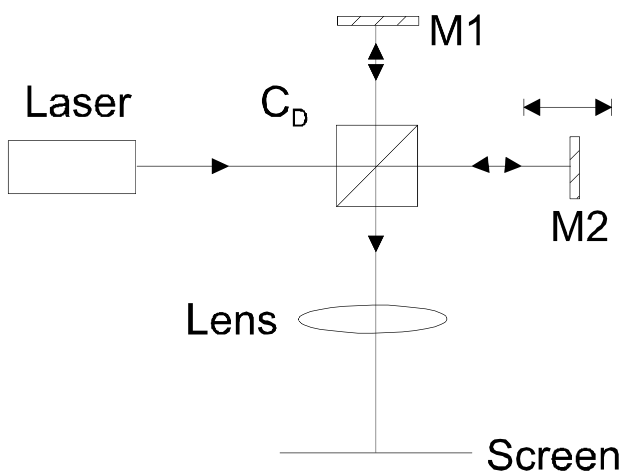

Figure 1

where M_1 , M_2 are, respectively, fixed and adjustable flat mirrors and C_D is a 50:50 cubic beam splitter. To facilitate the subsequent discussion, the following symbols are defined:

l_1 distance between M1 and the front reflecting surface of CD .085 m

l_2 distance between M2 and the back reflecting surface of CD .082 m

I_3 distance between the screen and the back reflecting surface of C_D 1 m

d path difference = $|l_2 - l_1|$ |.085 - .082| = .003 m

δ phase difference

δx fringe spacing

λ He-Ne laser wavelength – 632.8nm

α angular alignment error between M_1 and M_2

* It should be noted that all distances are expressed in meters while the angles are expressed in radians.

III. Procedure

A. Alignment

Mirror M2 could be mounted on a computer controllable translation stage. You could use the computer-controlled capability in part III.C. However, a manual translation stage will work as well.

The interferometer must be carefully set up in order to produce visible fringes:

1.Mount mirrors M_1, M_2 cubic beam splitter, laser, and the screen as shown in Figure 1 so that l_1, l_2, l_3 $\approx$ 0.05m and d < 0.0025m.

2.Further adjust M_1, M_2, and C_D so that $\alpha < 0.01$ radian while the reflecting surfaces of C_D is at 0.785 rad (45 degrees) with M_1 and M_2. (Alignment of the two mirrors can be achieved by placing a sharp object such as the tip of a pencil between the laser (turned off) and C_D.) Adjust the mirrors so that all the images of the sharp object are aligned.

3. Turn on laser, look into M_1 to search for the fringes. Avoid direct sighting of the laser!

4. If the alignment is successful, a series of vertical or horizontal fringes will appear.

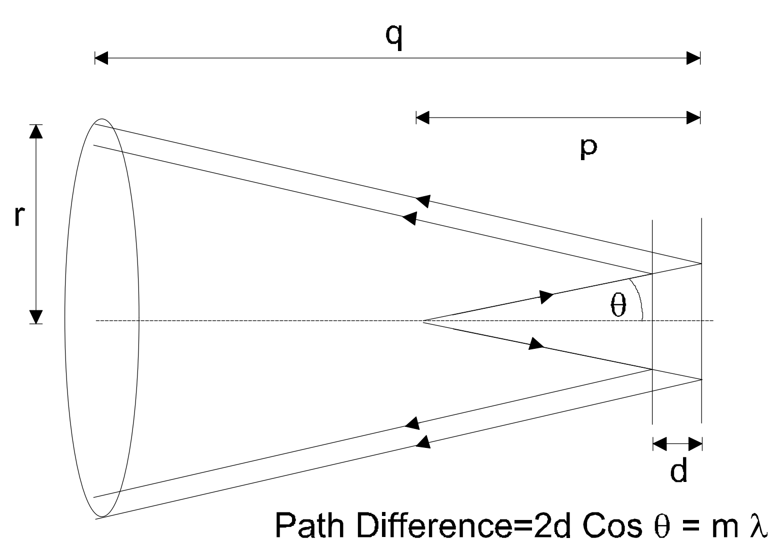

Figure 2:

B. Localized fringes

1. Slightly tilt M_2 so that $\alpha \approx 0.025$ rad, a set of vertical (localized) fringes should appear.

2. Slowly vary and observe the change in fringe patterns. Use the digital camera and take a picture of the fringes.

3. Calculate the magnification of the fringes due to the lens.

3. Calculate the angular alignment error according to:

$$a \approx \frac{l}{2\,\Delta x} \qquad (3)$$

where Δx is the spacing between adjacent ***unmagnified*** fringes.

C. Relative displacement measurement

1. With localized fringes, place a photodetector near the middle of the fringe pattern. The mirror M2 should be mounted on a computer-controlled translation stage. Connect the output of the photodetector to the oscilloscope.
2. Manually move the translation stage and verify that the detected signal varies as the fringes sweep past the detector.
3. Based on your observations, can you infer the *direction* of the translation based on the detected signal?
4. Using the supplied LABVIEW program, translate the stage about 50μm. (Make sure to account for the uncertainty in the starting position of the motor.) Record the transient waveform with the digitizing oscilloscope
5. Transfer the recorded waveform to the computer for further analysis.
6. By count the number of fringes m which sweep past the detector, verify that:

$$d = \frac{m\,l}{2}$$

7. What is the percent error in your measurement? What are the possible sources of error?

D. Circular Fringes

Circular fringes are difficult to align since the mirror mounts have only course adjustments. This portion of the lab is difficult to align and should challenge your optics skills. Exercise patience in your alignment! It may take a while to make fine adjustments to get circular fringes. The key feature is to align the tilt of the mirrors so that the vertical fringes are very wide. In addition, adjust the path difference *d* of the two interferometer path lengths to be very close to zero (less than 1mm). You should observe co-centric interference fringes. If you have difficulty with this portion of the lab, focusing the laser beam through an aperature and then collimating the beam at a larger diameter.

1. Slowing vary l_2 so that d is within a wavelength of the laser. Observe the disappearance of rings and the corresponding enlargement of the center fringe (black spot). Using the lab's digital camera, take a picture of the fringe pattern to be included in your lab report.

2. Verify that at $d = 0$, all rings will disappear. Explain this effect.

3. Increase d slightly until you get rings. Refering to Figure 2, measure, Δr, the fringe spacing (distance between two adjacent rings). To do this, use the lab's digital camera to take a picture of the fringe pattern on the screen. You will find it helpful to hold a ruler next to the screen when you take a picture so that you can later determine the fringe spacing. Make sure to record the focal length of the lens and the distance from the screen to the lens and the lens to the beamsplitter. You will need these values to determine the magnification of the fringe spacing due to the lens.

4. Based on the focal length of the lens and the distance to the screen, calculate the magnification of the fringes.

5. From Figure 2, the radius of the rings is given by:

$$r = 2\,l\,\tan\left[\arccos\left(\frac{m\,l}{2\,d}\right)\right] \qquad (1)$$

where $l=p+q$ and m is an integer. Verify that the experimentally measured ***unmagnified*** fringe spacing Δr is described by the following equation (differential of Eq.(1)):

$$\Delta r = \frac{2\,ld}{m^2\,l}\left[\frac{1}{\sqrt{1-\left(m\,l/2\,d\right)^2}}\right] \qquad (2)$$

The value of m can be determined by Eq.(1) by knowning d, l, and r for a particular ring.