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MEASUREMENT OF REFRACTIVE INDEX USING A MICHELSON INTERFEROMETER

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***Abstract*—As a classic laboratory apparatus, Michelson interferometer has been widely used in optical field. Under the premise of not affecting its accuracy, the operational performance of the Michelson interferometer should be improved. The Michelson interferometer can be used for the measurement of refractive index. For reduce experimental sensitivity, the structure of the Michelson interferometer is improved. Experimental results are demonstrated.**

Keywords—**Michelson interferometer, refractive index, measurement**

I. INTRODUCTION

Michelson interferometer, a typical sub-amplitude interferometer, was co-invented by American physicist Michelson and Morey in 1883. This sophisticated optical instrument is targeted to study the "ether" drift, finally proving that the ether does not exist [1, 2].

The Michelson interferometer is an optical instrument utilizing the method of dividing the amplitude of the optical wave to realize the interference. It promotes the establishment of relativity and makes a great contribution to the development of physics. At present, a variety of precision instruments made based on the basic principles of Michelson interferometer have been widely used in the field of production and research. The most notable application of the Michelson interferometer is the zero result in the observation of the solar wind in the Michelson-Morley experiment. The dark clouds in the classical physics sky at the end of the nineteenth century provided experimental basis for the basic assumptions of the theory of relativity. In addition, since the laser interferometer can accurately measure the optical path difference in the interference, the Michelson interferometer and other kinds of interferometers have been widely used in today's gravitational wave detection. The basic principle of the laser interference gravitational wave observatory (LIGO) and many other ground laser interference gravitational wave detectors is to measure the optical path change of the laser caused by gravitational waves. The basic assumption of applying the Michelson interferometer has also been proposed to be used in the planned laser interference space antenna (LISA). The Michelson interferometer is also used in the search for extrasolar planets, although the Mach-Zehnder interferometer is more frequently used in this filed. The Michelson interferometer is also used in the delay-interferometer that is the manufacture of optic differential phase-shift keying demodulator which can convert phase modulation into amplitude modulation in wavelength division multiplexing network [3-6].

Michelson interferometer, the classic interference experimental instrument, famous for its high accuracy and simple structure is widely used in teaching and scientific experiment. However, high accuracy requires higher experimental sensitivity, the experimental environment as well as the operation of the instrument, such as the need of a laser with high interference performance, an anti-seismic optical platform, and the need to move the plane mirror in a fixed direction to reduce the pitch difference. Therefore, the key to widely use Michelson interferometer is to improve its operational performance under the premise of not affecting its accuracy. The Michelson interferometer can be used for the measurement of length and refractive index. This paper is targeted to the simple improvement of the basic structure of the interferometer so as to reduce its sensitivity.

II. THE BASIC PRINCIPLE OF THE MICHELSON INTERFEROMETER

Figure 1 is the schematic diagram of Michelson interferometer. A beam splitter was located in the center was placed in a 45-degree angle with the light screen position. With it as the center, there are two adjustable plane mirrors in both directions, if necessary, a compensation plate (not shown) will be added to one of them. When the light beam reaches the beam splitter, the beam will be divided into b1 and b2, and then projected toward the plane mirrors M1, M2. Finally, they will be reflected back to the spectroscope and rejoined. But when the arms- the distance between spectroscope and two planes- are different, light beam will travel different distance. Therefore, when they merge and meet through the same path to reach the screen, interference will occur because of path difference or phase difference.

Error! Reference source not found. Here we analyze the principle from the interference theory: the beam b1 is directed to the plane mirror M1 and reflected back to the beam splitter. In this process, the optical path is

$$\overline{OP_1}=n_1L_1$$ **Error! Reference source not found.** (1)

L1 is the distance from BS to M1, n1 is the relative refractive index of this branch.

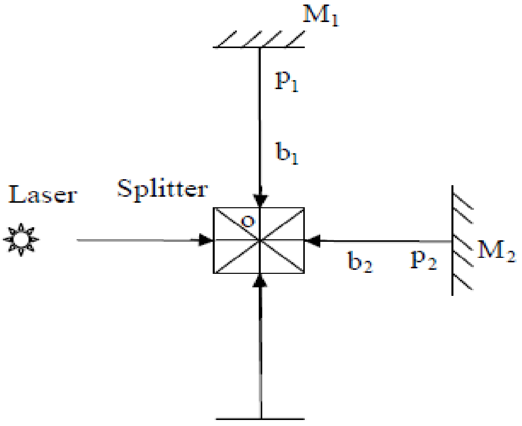

Fig. 1. Diagram of Michelson Interferometer

Beam b2 is directed and returns along $\overline{OP_2}$, the optical path is

$$\overline{OP_2}=n_2L_2$$ **Error! Reference source not found.**(2)

The two beams emerge in the beam splitter. The total optical path difference is

$$\Delta L = 2\left|\overline{OP_1}-\overline{OP_2}\right|$$ **Error! Reference source not found.** (3)

The phase difference of the recombination of the two beams is

$$\Delta\varphi = \frac{2\pi}{\lambda}\Delta L$$ (4)**Error! Reference source not found.**

where, λ is the wavelength of the light wave. When the distance between the two plane mirrors remains the same, the phase difference can be kept constant. Then a stable pattern of interference is projected on the screen.

When the image of one of the plane mirrors is tilted, the situation becomes equal-thickness interference. We assume that: when the mirror M1 rotates around the Y axis at a degree of $\alpha/2$, the mirror M2 remains perpendicular to the direction of light propagation. The beam from M1 to M2 forth and back will have an additional optical path

$$2\Delta L(x) = 2n_1 x\tan(\frac{\alpha}{2}) \approx n_1 x\alpha$$ **Error! Reference source not found.** (5)

x is the distance from the point on the mirror to the axis.

It can be seen that the phase size is linearly related to x, which makes the equidistant parallel stripe appear on the observation surface. The spatial frequency is $f_s = \alpha/2$.Even if optical path difference of the two beams which emitter by the same light source is very small, interference stripes will also show a very high contrast.

III. APPLICATION OF MICHELSON INTERFEROMETER

A. Experimental principle

We put two optical wedges in the opposite direction at one of the Michelson interferometer, and simultaneously moving the two wedges, w1 and w2, at the x direction, as shown in Figure 2.

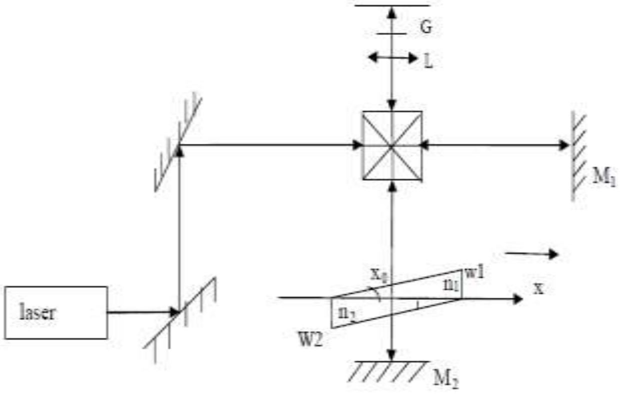

Fig. 2. Diagram of improved Michelson interferometer

Assuming the inclinations of the two wedges are α_1 and α_2. The refractive indices are n_1 and n_2, respectively. When the wedges moves a Δx distance, the optical path difference changes to

$$\Delta L = \left[(n_1-1)\alpha_1 - (n_2-1)\alpha_2\right]\Delta x \qquad (6)$$

This is only the optical path changes when light passing through the optical wedge once. For the Michelson light path, the light passes through the optical wedge twice, doubling the result of optical path changes.

When the upper and lower wedges are exactly the same optical wedge, that is their inclination and refractive indexes are the same and there are no changes on optical path difference in the optical path. There is no fringe movement on the interference screen.

When there is different refractive index between the upper and lower wedges, the difference value in the above bracket is not zero as wedge moving. When the inclination and refractive index of one of the optical wedges are known, then there is one unknown quantity. It can be solved from the above formula.

When the two wedges' inclination and the refractive index are different, the properties of the unknown wedge can be determined by the known optical wedges. When the wedge is out of factory, its inclination can be well controlled. Therefore, the inclination of the unknown optical wedges is easy to get, and its refractive index is also not difficult to get through the formula.

When the refractive index and inclination are fixed, the variable is the lateral distance x. Then, the vertical offset fringes along the x direction are obtained.

B. Experimental Results

Here we use the formula (N is the number of fringe cycles):

$$2\left[(n_1-1)\alpha_1+(n_2-1)\alpha_2\right]\Delta x = N\lambda \qquad (7)$$

Every 20 fringes movement cycle is a measurement unit, measured four sets of data and each group with 10 measurement units. After the measurement, removing the maximum and minimum value of each group and 32 data is finally got, as shown in table 1.

Table 1 Records of 20 fringes' pitch (unit: mm)

	1	2	3	4
Δx_1	0.137	0.146	0.143	0.148
Δx_2	0.135	0.141	0.135	0.142
Δx_3	0.155	0.130	0.145	0.149
Δx_4	0.145	0.139	0.145	0.138
Δx_5	0.140	0.155	0.143	0.135
Δx_6	0.149	0.142	0.138	0.138
Δx_7	0.152	0.145	0.145	0.147
$\overline{\Delta x}$	0.144	0.143	0.143	0.143

From Table 1, we can obtain $\overline{\Delta x} = 0.143 \pm 0.005$ mm.

By simply deduction, we get $n_2 = 1.563 \pm 0.056$ and its relative error is 3.5%.

Through the experiment, there are the following shortcomings: As a result of using semiconductor lasers to get a clear image for observing, there is a lens with 200 cm focal length between the screen and the instrument to enlarge the interference pattern. In the adjustment of the wedge, the difficulties encountered since we did not have a good way to make the splicing surface and the direction of light transmission strictly vertical. At the same time, we could not guarantee the cross section of the optical wedge in the absolute level, which brought to big error for measurement.

At the time of two wedges in bonding, there was no guarantee that the two wedges surface strictly merged. These are the limitations brought by experimental equipment, and also the shortcomings of the experiment.

IV. CONCLUSION

It can be seen from the experimental apparatus and the experimental process that the high sensitivity of the Michelson interferometer is reduced by the measured two wedges. Now we keep the moving distance at 0.1mm. The device can be operated with a manual mobile platform with a spiral micrometer. It can visually measure the number of fringe variations to make it easier for us to apply to practice as well as to the measurement of optical instruments. In addition to the use of double wedge measurement method, the single-wedge optical path measurement method can also be adopted. We can also bond other different shapes of optics together (such as the combination of the wedge and the lens, and the combination of the lens group), and even some fixed optical path group can be added to the Michelson optical path (such as directly adding the Newton ring, Huygens lens group, the Galileo telescope group, etc.). We can also change the angle of the parallel plane brick, to convert it into the form of optical wedges to have a measurement. It can be said that the use of this experimental device is widely and its improvement space is still very large.

For the single-wedge optical path, there are limitations and shortcomings so that the small inclination of the optical wedge is rarely used in the daily teaching and use. When we had an experiment, we had not found a suitable wedge. But for this optical path, the effect of small inclination can also be realized even if the wedge inclination is large so that the selection scope is greatly expanded.

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