Expt. 22 Michelson interferometer

Ⅰ. Purpose

(1) Understand the theory, construction, adjustment and operation of the Michelson interferometer;

(2) Learn the method of measurement of length using the Michelson interferometer.

Ⅱ. Apparatus

Michelson interferometer, He-Ne laser, sodium lamp, cover glass, ground glass, observing panel with scales.

Ⅲ. Principle

As shown in Figure 22 – 1 (a), a beam of parallel light travels from left to right to a beam-splitting lens. On passing through it is divided into two beams at the second surface of the beam-splitting lens (which is silver-gilt): One beam is reflected by the surface of the beam-splitting lens and then travels along one arm to the fixed plane mirror M_1, and is reflected towards the beam-splitting lens and pass through it. The other beam travels along the other arm to the plane mirror M_2, and is also reflected towards the beam-splitting lens and is reflected at the surface of it. The two beams of light interfere upon superposition and move towards the observation screen, forming beautiful interference fringes.

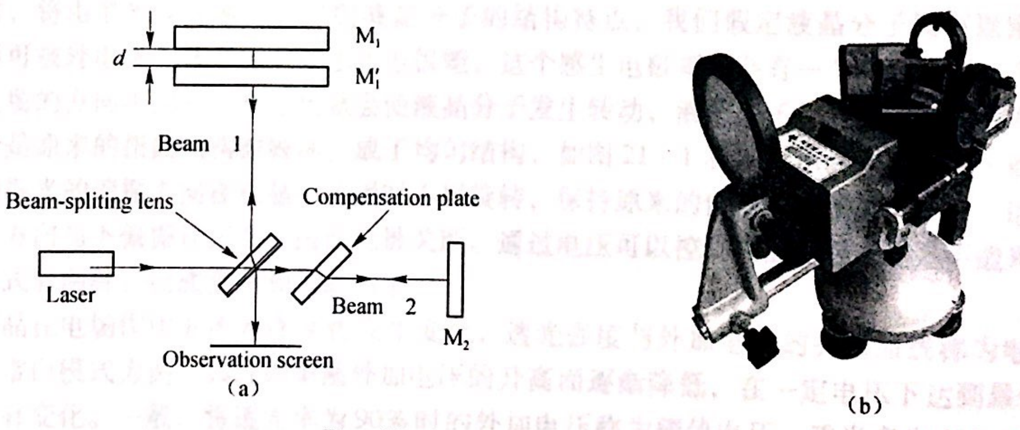

Figure 22 – 1 Michelson Interferometer

When the Michelson interferometer is used for measuring or calibrating one arm is always fixed. In this case M_2 is fixed and M_1 is moving. As M_1 is moved the interference pattern changes by

N fringes and the displacement Δd of M_1 is given by

$$\Delta d = N\frac{\lambda}{2} \tag{22-1}$$

If the interference fringes are adjusted until they are clear and wide, then Δd can be readily measured from the movement of fringes.

Ⅳ. Experimental

1. Adjustment of the Michelson interferometer

(1) Turn on the He-Ne laser, set it approximately horizontal and make sure that the laser beam is parallel to the plane of the interferometer track. Adjust the three horizontal screws at the bottom of the interferometer to make sure that the laser beam reaches to the centre of M_1 and M_2 at the same time, after the beam has been split at the centre of the beam-splitting lens.

(2) Adjust the mirror adjustment screws on the back of M_1 and M_2, to make sure that the central maximum light spots reflected from M_1 and M_2 arrive at the exit hole of the interferometer and superpose with each other.

(3) Once they superpose you can observe that the central maximum of the interference pattern appears black fringes. Keep on adjusting the screws of M_2 and do not move those of M_1 to make the fringes as wide as possible.

2. Observation of interference fringes of equal inclination

Adjust the height and position of the beam-expanding lens, so that the laser beam illuminates the entire beam-splitting lens P. Adjust in turn the "vertical adjusting screw" and the "horizontal adjusting screw" at the bottom of M_2, so that you can observe the concentric annular fringes of equal inclination.

3. Observing the change of equal inclination fringes and analyzing the relationship between the change and the optical path difference of the two light beams

Adjusting the remote barrel wheel d, observe the fringes "disappearing" and "appearing" at the centre, and the change of width. Further more, you should determine the relationship between these phenomena and the optical path difference of the two light beams.

4. Measuring the wavelength of the He-Ne laser

The arm with the mirror M_2 is fixed while the other mirror M_1 is allowed to move along one direction. If you count the number of interference fringes N which pass a fixed point when the mirror M_1 moves from an original position d_1 to a final position d_N, you can find the displacement Δd, of M_1. This is related to the wavelength λ by

$$\lambda = \frac{2\Delta d}{N} = \frac{2(d_N - d_1)}{N} \tag{22-2}$$

The procedure required is as follows:

Adjust the vertical and the horizontal adjusting screws under the mirror M_2 to move the annular interference fringes to the visual centre of the observation screen. Record the readings on the ruler scale, the barrel wheel D, and the remote barrel wheel d. Then turn the remote barrel wheel d along one direction while 100 fringes appear or disappear from the central light spot. Record the new reading of the position of M_1, d. Record 10 sets of data totalling 1000 fringes.

5. Observation of localized fringes

Localized fringes are obtained by adjusting the "mirror adjusting screws" on the back of M_2 and the vertical (or horizontal) remote screws and the remote barrel wheel, once the concentric annular fringes of equal inclination are observed. The interference fringes are observed to become wider and straighter. These are the well known localized interference fringes from the usual interference of light.

6. Observation of the interference of white light

As the white light comprises all colours with various wavelengths, besides the central nil-level bright fringe, the conditions for a bright fringe at a certain wavelength will coincide with the condition for a dark fringe at another wavelength. This makes it difficult to observe interference fringes for white light. To observe white light fringes the optical path difference between the two arms must be close to zero.

Determine the direction of movement of the barrel wheel D and remote barrel wheel d, when the fringes shrink and the central light spot disappears.

When the width of the fringes is about 7 – 8mm (about 1.5 divisions on the scales of the ground glass) and the fringes are comparatively straight then the optical path difference of the two arms is close to zero.

7. Measurement of the refractive index of a solid

The refractive index of a solid can be determined using the interference of white light. Here cover glass, which is a translucent and isotropic solid, will be used as the unknown sample. The schematic diagram of the optical path is shown in Figure 22 – 2.

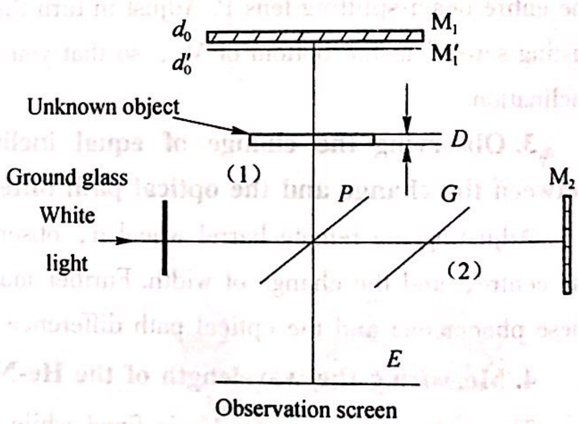

Figure 22 – 2 Determination of the Refractive Index of a Solid Using the Michelson Interferometer

In this experiment we use white light fringes. Firstly, adjust the apparatus and obtain white light fringes. Put the central dark fringe and coloured fringes on the visual centre of the observation screen. Record the position of M_1. Then insert the cover glass with thickness D and refractive index n into the M_1 arm. Turn the barrel wheel D and the remote barrel wheel d anticlockwise, moving the mirror M_1 towards the beam-splitting lens P, decreasing the geometric distance between M_1 and P. Make sure the white light fringes appear at the visual centre again. Record the new position of M_1. The displacement of M_1, ΔL, is the optical path difference added by inserting the cover glass, and $\Delta L = (n-1)D$, so we have

$$n = \frac{\Delta L}{D} + 1 \qquad (22-3)$$

According to this formula, if the thickness D of the cover glass is known, the refractive index of translucent solid can be worked out. Conversely, if the refractive index is known, the thickness can be determined.

Ⅴ. Questions

1. How does the distance between the laser and the beam-splitting lens P affect the observation the of the interference fringes of equal inclination? Does the position of the fringes of equal inclination change if the distance between the observation screen E and the beam-splitting lens P is changed? Does this affect the radius of the annular interference fringes? Try to explain all of your answers.

2. Why are white light fringes, which are difficult to obtain, used to measure the refractive index of the cover glass? Why do we not choose instead fringes of equal inclination, which are easily observed and measured?

实验二十二　迈克耳逊干涉仪

一、实验目的

(1) 熟悉迈克耳逊干涉仪的原理、结构和使用方法。

(2) 掌握利用迈克耳逊干涉仪测量长度的技术。

二、实验仪器

He－Ne 激光器、迈克耳逊干涉仪、盖玻片、毛玻璃、观察屏。

三、实验原理

如图 22－1 (a) 所示，激光器发出的一束平行光沿水平方向射向分束镜，穿过分束镜的第一个表面后，在其镀有银薄膜的第二个表面上分成两束光。其中一束光被反射后垂直射向平面镜 M_1，再被 M_1 反射后沿原路返回，穿过分束镜，射向观察屏。另一束光则穿过分束镜、补偿板后射向平面镜 M_2，再被 M_2 反射后沿原路返回到分束镜，经银薄膜表面反射后，与被 M_1 反射的第一束光一起射向观察屏。这两束光发生干涉，在观察屏上形成干涉条纹。

利用迈克耳逊干涉仪进行长度测量或校准时，通常是保持其一个臂固定，而使另一个臂移动。本实验设置 M_2 镜不动，而令 M_1 镜移动，此时干涉条纹随之移动。调节干涉条纹至清晰可辨时，可对 M_1 的移动距离进行精细的测量。当条纹移动 N 个时，可算得 M_1 的移动距离 Δd 为：

$$\Delta d = N\frac{\lambda}{2} \qquad (22-1)$$

四、实验内容和步骤

1. 迈克耳逊干涉仪的调节

(1) 观察并调整 He－Ne 激光器装置，使其保持水平。打开电源，使出射的激光束与干涉仪导轨相平行。反复微调干涉仪基座下面的三个“水平调节螺丝”，使得经过分束镜后的两束光能够同时入射到平面镜 M_1 和 M_2 的正中位置。

(2) 反复调节 M_1、M_2 背面的三颗“镜面调节螺丝”，以便使得经 M_1 和 M_2 所反射的光束的中间最大光斑与激光器的出射孔正中相重合。

(3) 两个光斑重合以后，在中间最大且最明亮的那个光斑上可以看到黑色的干涉条纹。这时应继续调节 M_2 上的调节螺丝（M_1 镜保持不动），尽量使得光斑上的干涉条纹粗大清晰。

2. 观察等倾干涉条纹

调整扩束镜的方向和高度，使得通过扩束以后的激光束照亮整个分束镜。同时调节 M_2 下面的“水平微调螺丝”和“垂直微调螺丝”，直到可以看到清晰的同心、圆环状的等倾干涉条纹。

3. 观察并分析干涉条纹的变化与两光束间光程差的关系

微动调节鼓轮 d，可以观察干涉条纹的“吞”、“吐”情况以及条纹的“粗”、“细”变化，分析这些现象与两光束之间光程差的关系。

4. 测量氦氖激光器的光波波长

固定平面镜 M_2，而使另一个平面镜 M_1 沿着同一个方向移动，这时从观察屏上可观察到干涉条纹的移动。在 M_1 镜从起始位置 d_1 移动到终了位置 d_N 的过程中，如果条纹移动了 N 个，这时 M_1 的移动距离 Δd 可确定为

$$\lambda = \frac{2\Delta d}{N} = \frac{2(d_N - d_1)}{N} \qquad (22-2)$$

具体操作步骤如下：

微调 M_2 下面的水平和垂直调节螺丝，使得环形干涉条纹处于观察屏的视场中心，同时记下此时 M_1 的位置读数（标尺读数 + 鼓轮 D 读数 + 微调鼓轮 d 读数）。接下来沿同一方向轻缓转动微调鼓轮 d，观察 100 个中心光斑的涌出（或消失），并再次记下此时 M_1 的位置读数 d。考察 10 组总共 1000 个干涉条纹的单方向变化情况。

5. 观察等厚干涉条纹

获得等厚干涉条纹的方法是：在调出同心、圆环形的等倾干涉条纹后，调节 M_2 下面的垂直（或水平）微调螺丝和背面的“镜面调节螺丝”以及微调鼓轮 d，这时可以观察到干涉条纹逐渐变直、变粗，这时的条纹就是等厚干涉条纹，类似于在光的干涉实验中所已经熟悉的条纹。

6. 考察白光干涉

因为白光中含有各种不同波长的光，所以除了中央零级明条纹外，会发生某个波长的光的某一级次的衍射明条纹正好落在另一波长的光的暗条纹上，导致高级次的干涉条纹难以观测的现象。白光干涉只发生在光程差接近于零的一个极小范围内。

确定干涉条纹向中心收缩、同时中心光斑被逐渐吞没时鼓轮 D 和微调鼓轮 d 的转动方向。

调节干涉条纹使其宽度达到 7 ~ 8mm（在毛玻璃上观察刻度约为 1.5 格），这时的干涉条纹应当已经比较直，这意味着沿两臂行进的光束之间的光程差已接近于 0。

7. 测量固体的折射率

利用白光干涉条纹的特点，可以观测透明固体介质的折射率。本实验以各向同性、透明的固体介质盖玻片作为测量对象来进行折射率测量的练习。其测量的原理光路如图 22 - 2所示。

实验采用白光作为光源。首先调出白光干涉条纹，接着使得零级干涉条纹和彩色条纹显现在观察屏中央，记录下此时动镜 M_1 的位置。插入折射率为 n、厚度为 D 的盖玻片于 M_1 所在的臂。沿逆时针方向转动鼓轮 D 和微调鼓轮 d，使得 M_1 镜向着分束镜 P 的方向移

动。随着 M_1P 之间几何距离的缩短，白光干涉条纹将再次显现在视场中央。再次读出 M_1 在此时的位置。这时 M_1 自始至终所移动的距离 ΔL 就是插入介质薄片后所产生的光程差，即$\Delta L = (n-1)D$，由此可得

$$n = \frac{\Delta L}{D} + 1 \tag{22-3}$$

显然，如果盖玻片的厚度 D 已知，就可以据此式求得此透明固体介质的折射率。反之，如果此透明介质的折射率已知，则可以求得它的厚度。

五、思考题

1. 解释：改变激光器与分束镜之间的距离，或者改变观察屏与分束镜的距离，等倾干涉条纹的级数是否改变？圆环状等倾干涉条纹的各级半径是否也会改变？

2. 在观测透明盖玻片的折射率时，为什么利用较难调节的白光干涉现象，而不是采用易观察和易测量的等倾干涉方法？

实验十五　迈克尔逊干涉仪

1. 观察非定域圆形干涉条纹

干涉条纹的变化	向外"吐"	向中心"吞"	条纹变疏	条纹变密
h 的变化				
原因解释				

2. 校准干涉仪的刻度

N	$\Delta h = N\lambda/2$	M1 镜的位置 $\Delta L = \lvert L_2 - L_1 \rvert$ (mm)			$\lvert \Delta L - \Delta h \rvert$ (mm)	$\lvert \Delta L - \Delta h \rvert / \Delta h$
		L_1	L_3	ΔL		

3. 观察白光干涉条纹

等光程点的位置/mm	白光干涉条纹的特点

4. 测固体折射率 nM_x

无盖玻片时 M_1 的位置/mm	有盖玻片时 M_1 的位置/mm

思考题