重庆大学-辛辛那提大学联合学院

学生实验报告

CQU-UC Joint Co-op Institute (JCI)
Student Experiment Report

实验课程名称 Experiment Course Name 大学物理实验（I）

开课实验室（学院）Laboratory (School) JCI

学院 School CQU-UC 年级专业班 Student Group 18ME01

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学年 Academic Year 2019 学期 Semester Spring

成绩 Grade	
教师签名 Signature of Instructor	

批改说明 Marking instructions:

指导老师请用红色水笔批改，在扣分处标明所扣分数并给出相应理由，在封面的平时成绩处注明成绩。

Supervisors should mark the report with a **red ink pen**. Please write down **the points deducted** for each section when errors arise and specify the corresponding reasons. Please write down **the total grade** in the table on the cover page.

重庆大学-辛辛那提大学联合学院 2016 年制订

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姓名 Name 易弘睿 学号 Student Number 20186103

开课学院、实验室 Academic School/ Laboratory CQU-UC

实验时间 Date of Experiment 2019 年 Year 03 月 Month 12 日 Day

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<table>
<tr><td rowspan="2">课程名称
Course Name</td><td rowspan="2"></td><td rowspan="2">实验项目名称
Experiment Project</td><td rowspan="2"></td><td colspan="5">实验项目类型
Type of experiment project</td></tr>
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Verification</td><td>演 示
Presentation</td><td>综 合
Comprehensive</td><td>设 计
Design</td><td>其 他
Others</td></tr>
<tr><td>指导老师
Supervisor</td><td></td><td>成绩
Grade</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

实验目的 Description/Instruction:

The vibration generated by the vocal body propagates in the air or other substances called sound waves. Sound waves propagate in all directions by means of various media. Sound waves are usually longitudinal and transverse waves. Particles near the equilibrium position vibrate along the propagation direction. Sound wave propagation is essentially the transmission of energy in the medium. Acousto-optic interaction has become one of the most practical methods to control the intensity and propagation direction of light. Acousto-optic deflector and acousto-optic modulator have been made by using this effect to control the frequency, intensity and propagation direction of light beam. Among them, acousto-optic transmission technology has been widely used. In this experiment, we need to understand the mechanism of acousto-optic interaction and the principle of ultrasonic grating, observe the phenomenon of acousto-optic diffraction, and learn to use ultrasonic grating to measure the sound velocity in liquid.

原理和设计 Principle and Design:

When sound waves propagate in gas and liquid media, the density of medium varies in density alternately and the liquid acoustic field is formed. When light passes through this acoustic field, it is equivalent to passing through a transmission phase grating and diffraction occurs. This kind of transmission is called "acoustooptic diffraction". The medium with acoustic field is called "acoustooptic grating". When using ultrasound, it is usually called "ultrasonic grating". The purpose of this experiment is to study the diffraction effect of ultrasonic grating with liquid medium on light.

Ultrasound propagates in liquid either by traveling wave or standing wave type of ultrasonic grating. The grating surface moves with time in space. Fig.1 shows the situation of acoustic traveling wave in a moment. Fig.1 (a) shows the periodic density distribution of dense phases in liquid when there is an ultrasonic field. Fig.1 (b) shows the corresponding refractive index distribution, and no indicates the liquid when there is no ultrasonic field. The refractive index of the body is visible from the graph. The density and refractive index of the body vary periodically and have the same period. The corresponding wavelength is the wavelength of the ultrasonic wave H. Because it is traveling wave, the distribution of the refractive index advances with the velocity of sound V and can be expressed as:

$$\mathrm{n}(\mathrm{Z},\mathrm{t}) = n_0 + \Delta n(Z,t)$$

$$\Delta(\mathrm{Z},\mathrm{t}) = \Delta \mathrm{n} \sin(k_s Z - \omega_s t)$$

In the formula, Z is the coordinate of the direction of ultrasonic propagation, $K_s = 2\pi/\lambda_s$, λ_s is the wavelength of ultrasonic wave, and the refractive index increment $\Delta n(Z,t)$ varies according to sinusoidal law.

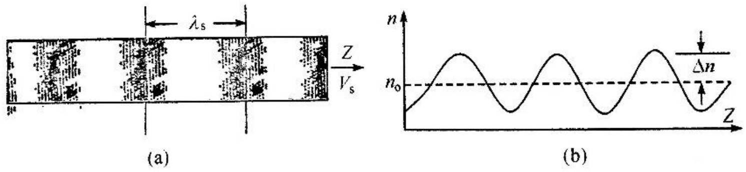

Figure1: Acoustic Waves of Mediumin Liquids

If a reflecting surface is set vertically in the proper position in the forward direction of the ultrasonic wave, the ultrasonic standing wave can be obtained for the ultrasonic standing wave. It can be considered that the ultrasonic grating is a space-fixed forward wave and the equation of the reflected wave are as follows:

$$\begin{cases} a_1(Z,t) = Asin2\pi(\frac{t}{T_s} - \frac{Z}{\lambda_s}) \\ a_2(Z,t) = Asin2\pi(\frac{t}{T_s} - \frac{Z}{\lambda_s}) \end{cases}$$

Add up the two items, $a(Z,t) = a_1(Z,t) + a_2(Z,t)$, we can get:

$$a(Z,t) = 2Acos2\pi\frac{Z}{\lambda_s}sin2\pi\frac{t}{T_s}$$

The result shows that the superposition results in a new acoustic wave; the amplitude is$2\mathrm{Acos}(\frac{2\pi Z}{\lambda_s})$, i.e. the amplitude of each point in the Z direction is different and changes periodically, and the wavelength is h, which does not change with time; the phase $2\pi t/T_s$ is a function of time, but does not change with space, which is the characteristic of ultrasonic standing wave.

The calculation shows that the corresponding refractive index change can be expressed as:

$$\mathrm{a}(\mathrm{Z},\mathrm{t}) = 2\Delta \mathrm{n} \sin K_s Z \cdot cos\omega_s \mathrm{t}$$

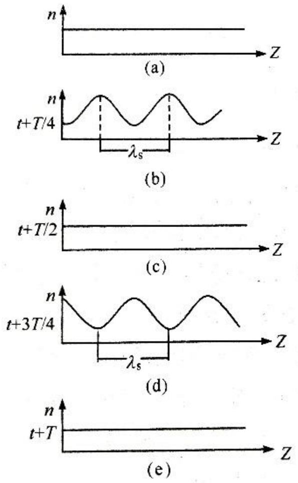

Figure 2:
Refractive Index
Distribution in Ultrasound

The symbols in the formula have the same meaning as before, and the corresponding images are shown in Fig. 2. It can be seen that the distribution of 0n (Z, t) is different at different times. That is to say, for any point in space, the refractive index changes with time, the period of change is Ts, and the refractive index of some points on the corresponding Z axis can reach the maximum or minimum value; for the same time, the refractive index on the Z axis is also periodic. Sex distribution, its corresponding wavelength is in. In a word, the grating constant of standing wave ultrasonic grating is the wavelength of ultrasound.

When a monochrome collimated light beam is perpendicularly projected onto an ultrasonic grating (the direction of light propagation is in the grating plane), the output light is diffracted light, as shown in Fig.3. In the figure, m is the number of diffraction orders and θ is the diffraction angle of the first order diffracted light. It can be proved that, like an optical grating, the conditions for the formation of all levels of diffraction are as follows:

$$\sin\theta_m = \pm\frac{m\lambda}{\lambda_s}\ (m = 0, \pm1, \pm2, \cdots)$$

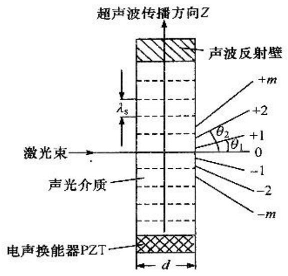

Figure 3:
Diffraction of Beams by
Ultrasound Grating

In the formula, λ is the wavelength of human light; λ_s is the wavelength of ultrasonic wave. Considering that the diffraction angle λ_s is small, there is $\sin\theta \approx \frac{X_m}{2L}$, and X_m is the distance between the spots of $\pm m$, if the wavelength n is known, the wavelength λ_s of ultrasonic wave can be measured. If the frequency of ultrasonic wave f_s can also be measured, the propagation speed of ultrasonic wave in the liquid is as follows:

$$V_s = \frac{2L\lambda f_s}{X_m/m}$$

The above method is one of the effective methods to measure the speed of ultrasonic propagation.

Raman-Nath diffraction is a kind of acousto-optic diffraction phenomenon which can produce multi-level diffraction. Only when the frequency of ultrasonic wave is low and the angle of attack is small, can it produce this kind of diffraction. Another kind of acousto-optic diffraction is called Bragg diffraction. It only produces zero-order and only-order+1 or-1-order diffraction. This kind of diffraction only produces high frequency of ultrasound, long acousto-light beam. Bragg traveling can occur only when people shoot at a certain angle, which is often used in optical deflection, optical modulation and other technologies. Raman-Ness diffraction is only involved in this experiment.

实验器材 List of instruments and materials:

SLD-II Acousto-optic Diffractor, Optical Tool Base, He-Ne Laser, Vernier Caliper, Meter Scale, Alcohol Thermometer.

In this experiment, the inverse piezoelectric effect of piezoelectric material-2 generates ultrasonic wave and ultrasonic standing wave field in liquid tank, forming ultrasonic grating piezoelectric material which acts as electroacoustic transducer here and produces ultrasonic vibration under alternating electric field. When the frequency of alternating voltage reaches the natural frequency of the transducer S in n, the output amplitude of the transducer reaches the maximum value due to resonance. Common materials with significant piezoelectric effect are quartz, lithium niobate and lead zirconate titanate (PZT) ceramics. The experimental setup is shown in Fig.4.

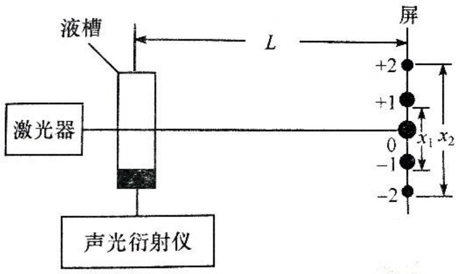

Figure 4: A Simple Acousto-Optical Diffraction Optical Path

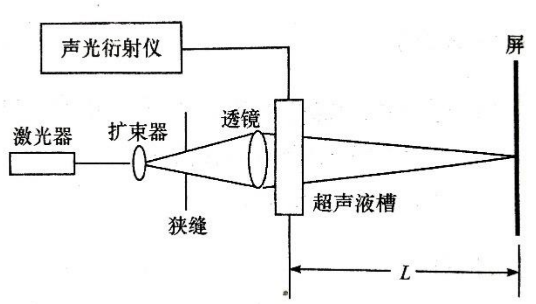

Figure 5: Recommended optical

实验步骤 Implementation:

(1) Arrange the optical path on the optical pedestal according to Figure 4.
(2) Install a proper amount of transparent liquid (water, alcohol or other liquid to be measured) in the liquid tank to minimize the bubbles on the wall of the tank and put the ultrasonic transducer into it. Open the laser and make the laser beam shoot vertically on the liquid tank.
(3) Connect the circuit, turn on and add excitation voltage to the transducer. Adjust the frequency adjustment knob of the acoustooptic diffractometer until the diffraction pattern appears on the observation screen.
(4) The pitch, azimuth, position of acoustic transducer and frequency adjusting knob of the instrument are adjusted carefully and repeatedly until the diffraction beam on the observation screen is the largest and the intensity of light is the largest.
(5) Measure the distance L from the center of the tank to the screen with a meter gauge and find the average value.
(6) Measure the distance X_m between the $\pm m$ spot with vernier (in order to avoid the mistake of finding the spot center, the distance between the same side edge of two same-level spot should be measured).
(7) Measuring the temperature of the liquid with a thermometer.
(8) Measure the frequency f_s of the ultrasonic oscillation. The sound velocity V at this temperature is calculated, and the average value
(9) is obtained. The temperature of liquid in the tank is changed, and the sound velocity at different temperatures is measured. The effect of temperature on the sound velocity is noticed.

Recommendations:
① Arrange the optical path according to Fig. 5 and make the components coaxially equal in height, adjust the slit width to the appropriate position and adjust the lens, so that a clear slit image appears on the screen.
② Repeat the experiment content (2) ~ (4) to make the diffraction slits on the observation screen appear most clearly and clearly.
③ Measure the distance X and F of L and slit images at all levels, and find the velocity of ultrasonic wave in the liquid.

实验结果和数据处理 Results and Data processing:

【Results】

声光衍射测声速数据记录表							
Temperature of Water(°C): 14.0 **Frequency of sound(Hz*10^6):** 11.18 **Wave length of light(nm):** 650.4	**Distance L(mm)**	**L1**	**L2**	**L3**	**L4**	**L5**	**Average $\bar{L}$**
		535.50	536.00	535.50	536.50	536.00	535.90
	Spots separation X_m/m (mm)	$X_1^1/1$	$X_1^2/1$	$X_1^3/1$	$X_1^4/1$	$X_1^5/1$	**Average $\overline{X_1}/1$**
		4.40	4.46	4.26	4.54	4.60	4.45
		$X_2^1/2$	$X_2^2/2$	$X_2^3/2$	$X_2^4/2$	$X_2^5/2$	**Average $\overline{X_2}/2$**
		4.94	4.69	4.81	4.92	4.78	4.83
		$X_3^1/3$	$X_3^2/3$	$X_3^3/3$	$X_3^4/3$	$X_3^5/3$	**Average $\overline{X_3}/3$**
		4.91	4.80	4.95	4.93	4.86	4.89
		Average $\overline{X_m}/m$					4.72
Temperature of Water(°C): 33.5 **Frequency of sound(Hz*10^6):** 11.18 **Wave length of light(nm):** 650.4	**Distance L(mm)**	**L1**	**L2**	**L3**	**L4**	**L5**	**Average $\bar{L}$**
		535.50	536.00	535.50	536.50	536.00	535.90
	Spots separation X_m/m (mm)	$X_1^1/1$	$X_1^2/1$	$X_1^3/1$	$X_1^4/1$	$X_1^5/1$	**Average $\overline{X_1}/1$**
		5.34	5.14	5.40	5.24	5.36	5.30
		$X_2^1/2$	$X_2^2/2$	$X_2^3/2$	$X_2^4/2$	$X_2^5/2$	**Average $\overline{X_2}/2$**
		5.31	5.20	5.30	5.20	5.29	5.26
		$X_3^1/3$	$X_3^2/3$	$X_3^3/3$	$X_3^4/3$	$X_3^5/3$	**Average $\overline{X_3}/3$**
		4.99	5.14	5.07	5.15	5.09	5.09
		Average $\overline{X_m}/m$					5.22

Table: Acousto-optic Effect Data Recording Form

【Data processing】

Calculation of Data:

1. The average distance $L = \frac{535.50+536.00+535.50+536.50+536.00}{5} = 535.90(mm)$.

2. When the temperature of water is 14.0°C:

$$\left.\begin{aligned} \text{Average } \frac{\overline{X_1}}{1} &= \frac{4.40+4.46+4.26+4.54+4.60}{5} = 4.45 \\ \text{Average } \frac{\overline{X_2}}{2} &= \frac{4.94+4.69+4.81+4.92+4.78}{5} = 4.83 \\ \text{Average } \frac{\overline{X_3}}{3} &= \frac{4.91+4.80+4.95+4.93+4.86}{5} = 4.89 \end{aligned}\right\} \text{Average } \frac{\overline{X_m}}{m} = \frac{\text{Average } \frac{\overline{X_1}}{1} + \text{Average } \frac{\overline{X_2}}{2} + \text{Average } \frac{\overline{X_3}}{3}}{3} = 4.72(mm)$$

$V_s = \frac{2\times535.90\times10^{-3}\times650.4\times10^{-9}\times9.22\times10^{6}}{4.72\times10^{-3}}$=1361.71m/s

3. When the temperature of water is 33.5°C:

$$\left.\begin{aligned} \text{Average } \frac{\overline{X_1}}{1} &= \frac{5.34+5.14+5.40+5.24+5.36}{5} = 5.30 \\ \text{Average } \frac{\overline{X_2}}{2} &= \frac{5.31+5.20+5.30+5.20+5.29}{5} = 5.26 \\ \text{Average } \frac{\overline{X_3}}{3} &= \frac{4.99+5.14+5.07+5.15+5.09}{5} = 5.09 \end{aligned}\right\} \text{Average } \frac{\overline{X_m}}{m} = \frac{\text{Average } \frac{\overline{X_1}}{1} + \text{Average } \frac{\overline{X_2}}{2} + \text{Average } \frac{\overline{X_3}}{3}}{3} = 5.22(mm)$$

$V_s = \frac{2\times535.90\times10^{-3}\times650.4\times10^{-9}\times11.18\times10^{6}}{5.22\times10^{-3}}$=1493.02m/s

Calculation of Uncertainties:

1. $\boldsymbol{U_A}$

(1) For L,

$$u_A = t_p\sqrt{\frac{\sum_{i=1}^{k}(L_i-\bar{L})^2}{k(k-1)}}=2.78\times\sqrt{\frac{(535.5-535.9)^2+(536.0-535.9)^2+(535.5-535.9)^2+(536.5-535.9)^2+(536.0-535.9)^2}{5\times4}}=0.708764$$

(2) When the temperature of water is 14.0°C:

For $\frac{\overline{X_1}}{1}$, $u_A = t_p\sqrt{\frac{\sum_{i=1}^{k}(X_i-\overline{X_1})^2}{k(k-1)}}=2.78\times\sqrt{\frac{(4.40-4.45)^2+(4.46-4.45)^2+(4.26-4.45)^2+(4.54-4.45)^2+(4.60-4.45)^2}{5\times4}}=0.163619$

For $\frac{\overline{X_2}}{2}$, $u_A = t_p\sqrt{\frac{\sum_{i=1}^{k}(X_i-\overline{X_2})^2}{k(k-1)}}=2.78\times\sqrt{\frac{(4.94-4.83)^2+(4.69-4.83)^2+(4.81-4.83)^2+(4.92-4.83)^2+(4.78-4.83)^2}{5\times4}}=0.128423$

For $\frac{\overline{X_3}}{3}$, $u_A = t_p\sqrt{\frac{\sum_{i=1}^{k}(X_i-\overline{X_3})^2}{k(k-1)}}=2.78\times\sqrt{\frac{(4.91-4.89)^2+(4.80-4.89)^2+(4.95-4.89)^2+(4.93-4.89)^2+(4.86-4.89)^2}{5\times4}}=0.075111$

(3) When the temperature of water is 33.5°C:

For $\frac{\overline{X_1}}{1}$, $u_A = t_p\sqrt{\frac{\sum_{i=1}^{k}(X_i-\overline{X_1})^2}{k(k-1)}}=2.78\times\sqrt{\frac{(5.34-5.30)^2+(5.14-5.30)^2+(5.40-5.30)^2+(5.24-5.30)^2+(5.36-5.30)^2}{5\times4}}=0.130867$

For $\frac{\overline{X_2}}{2}$, $u_A = t_p\sqrt{\frac{\sum_{i=1}^{k}(X_i-\overline{X_2})^2}{k(k-1)}}=2.78\times\sqrt{\frac{(5.31-5.26)^2+(5.20-5.26)^2+(5.30-5.26)^2+(5.20-5.26)^2+(5.29-5.26)^2}{5\times4}}=0.068661$

For $\frac{\overline{X_3}}{3}$, $u_A = t_p\sqrt{\frac{\sum_{i=1}^{k}(X_i-\overline{X_3})^2}{k(k-1)}}=2.78\times\sqrt{\frac{(4.99-5.09)^2+(5.14-5.09)^2+(5.07-5.09)^2+(5.15-5.09)^2+(5.09-5.09)^2}{5\times4}}=0.079801$

2. $\boldsymbol{U_B}$

Uncertainties	$\boldsymbol{U_B}$	
	$\boldsymbol{U_I}$	$\boldsymbol{U_E}$
卷尺(mm)	0.5	0.5
游标卡尺(mm)	0.02	0.02
温度计(°C)	0.5	0.5
声光衍射仪(MHz)	0.01	0.01

实验讨论 Discussions:

1. When the temperature changes, the refractive index of the liquid will change, and the parameters of the ultrasonic grating will also change. What effect does the temperature have on the sound velocity in the liquid?

According to Table: Acousto-optic Effect Data Recording Form, compare the data of 14.0 °C and 33.5°C , we can observe that the higher the temperature, the faster the sound travels in the liquid.

2. Why such change in the first discussion happens?

Sound wave is a kind of fluctuation. Sound source must pass through a certain medium before it can propagate outward. That is to say, sound wave depends on the vibration of the medium particle to transmit sound energy. When the medium changes (including the change of medium material, density and temperature), the sound transmission will also change, such as the change of sound speed and direction. Among many medium variations, the change of air temperature will change the sound velocity. This change is manifested in that the sound travels faster in high temperature air (the more active the gas molecule as the medium is, the faster the sound wave travels), and its velocity is proportional to the square root of thermodynamic temperature.