Expt. 15 Measurement of sound velocity

Ⅰ. Purpose

Learn to measure the propagation velocity of ultrasonic sound waves in air by the method of resonance and the method of phase comparison.

Ⅱ. Apparatus

Ultrasonic sound wave velocity meter, signal generator and dual trace oscilloscope.

Ⅲ. Principle

Ultrasonic sound waves propagate in the form of a longitudinal wave in elastic media (such as air), with the relation between the propagation velocity u, the frequency f and wavelength λ given by:

$$u = f\lambda \tag{15 - 1}$$

This experiment utilizes piezoelectric ceramic ultrasonic transducers to generate and measure the ultrasonic wave. The wavelength of the ultrasonic wave is of the order of mm. It can be approximately considered as a plane wave.

There are two methods to measure wavelength: **resonance interference** and **phase comparison.**

1. Method of resonance interference (standing wave method)

The plane ultrasonic wave emitted by the generator is reflected from the plane of the receiver. The emitted and reflected wave combine to form a standing wave. For a standing wave the positions of maximum sound pressure are called nodes. When the end face of the receiver is at such a position that largest electrical signal is generated. This can be observed on the oscilloscope. At a node the distance between the emitter and receiver is an integral multiple of half a wavelength. By moving the receiver you can observe on the oscilloscope that signal reduces and becomes large again. The distance between neighbouring large signals is $\lambda/2$ as shown in Figure 15 – 1.

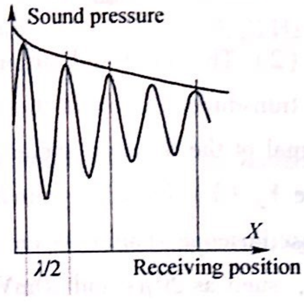

Figure 15 – 1 Relationship Between Sound Pressure and Receiver Position

2. Method of phase comparison (traveling wave method)

For a travelling wave the distance between two neighbouring positions with the same phase is one wavelength λ. By looking at the Lissajou figure shown in Figure 15 – 2 (obtained by combining two simple harmonic oscillations perpendicular to each other) you can determine the positions of the same phase or opposite phase and consequently measure the wavelength λ of the ultrasonic wave. Since the position of the oblique line (the Lissajou figure formed by two sine waves of the same frequency with a phase difference of 0° or 180° is easy to determine), this method is more accurate than the method of resonance.

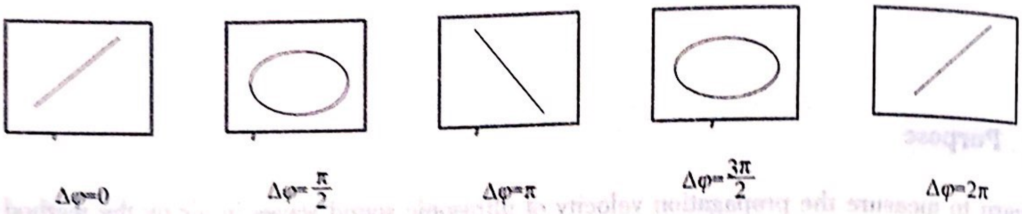

Figure 15 – 2 Lissajou Figure of 1:1 Combined by Same Frequency Perpendicular Oscillation

Ⅳ. Experimental

1. Structure of apparatus

(1) The ultrasonic sound velocity measuring instrument consists of the frame, vernier and two ultrasonic transducers. The relative positions of the ultrasonic wave emitter and receiver can be read directly by using the vernier (see Figure 15 – 3).

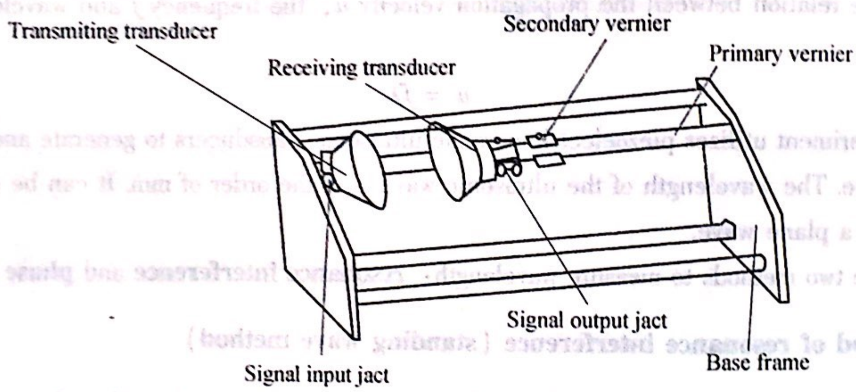

Figure 15 – 3 Diagram of the Ultrasonic Velocity of Sound Measuring Instrument

(2) The input and output jacks are red for signal and black for ground (instrument shell) for both transducers. Connect the input terminal of the emitting transducer to the T shape BNC OUTPUT terminal of the function signal generator and connect the output terminal of the receiving transducer to the Y_2 (Y) INPUT terminal of the dual trace oscilloscope. The working mode selecting switch of the oscilloscope should be on Y_2, with proper positions for T/div and V/div band selecting switches, such as 20μs and 20mV.

(3) Adjust the frequency of the function signal generator (with the function key in the SINE WAVE position, the frequency multiplication key on 100kHz) to observe the signal on the oscilloscope. Carefully adjust the output signal frequency of the signal generator until resonance state is observed. Here, with the oscilloscope displaying the maximum amplitude of received signal, the resonance frequency is the frequency f of the ultrasonic wave.

2. Standing wave method

Under conditions of resonance, start from by placing the receiving transducer near to the emitting transducer; gradually move the receiving transducer to a distant position. When the oscilloscope displays a signal of maximum amplitude, utilize the fine adjusting mechanism on the vernier scale to determine the position of the maximum resonance amplitude and record it. Record the values of the positions of maximum amplitude X_1, X_2, ..., X_{10}, X_{11}, X_{12}, ..., X_{20}, and then process the data by the method of successive differences, to give the average wavelength of the ultrasonic wave λ.

$$\bar{\lambda}_{共(相)} = \frac{\sum_{i=1}^{10}(X_{10+i} - X_i)/10}{10} \times 2$$

3. Traveling wave method

(1) Connect the other output of the T shape BNC OUTPUT terminal of the function signal generator to the Y_1 (X) INPUT terminal of the dual trace oscilloscope, making the sine wave from the signal source directly add to the X axis input terminal of the oscilloscope, whereas the output connection of the receiving transducer remains unchanged.

(2) Under condition of resonance frequency, adjust the face of the receiving transducer to a position which deviates slightly from perpendicular, to facilitate the observation of the combined trace on the oscilloscope.

(3) Observe the Lissajou figure on the oscilloscope, move the receiving transducer from near to far, record in turn the positions of the receiver at which the Lissajou figure changes from a ellipse to a rightward (or leftward) oblique line X_1, X_2, ..., X_{10}, X_{11}, X_{12}, ..., X_{20}. Then process the data by the method of successive differences to give the average wavelength of the ultrasonic wave λ. (Note: it requires a phase difference of π between each neighbouring pair of measurement points.)

When calculating the uncertainty of the velocity of sound, you should consider the error of the instruments. For the sound velocity meter vernier scale used in this experiment, the permissible error limit is 0.02mm. For the signal generator output frequency the permissible error limit is 0.2kHz.

Notes:

(1) In the experiment, you should firstly determine the resonant frequency of the piezoelectric transducer.

(2) During the experiment, you should adjust momentarily the Y_2 (Y) axis sensitivity stepping knob of the oscilloscope, to increase the measuring sensitivity.

V. Questions

1. Why should you measure the wavelength of the sound wave when the system is in a resonant state?

2. What are the main reasons for error in this experiment?

实验十五 声速测量

一、实验目的

学习利用共振法、相位法测量超声波在空气中的传播速度。

二、实验仪器

超声波声速测量仪，信号发生器，双踪示波器。

三、实验原理

超声波在弹性媒质中（如空气中）以纵波形式传播，其传播速度u与频率f及波长λ之间的关系为：

$$u = f\lambda \tag{15-1}$$

本实验中，使用压电陶瓷超声换能器实现超声波的产生和测量。超声波波长为毫米量级，定向性能好，且可以近似认为平面波。

波长的测量方法常见的有共振干涉和相位比较法两种。

1. 共振干涉（驻波）法

发射器发射出的平面超声波，入射到接收器的平面上被反射，在发射器与接收器之间人射波与反射波叠加形成驻波。由纵波的性质可以证明，当空气中形成驻波共振时，接收器端面位于振动波节处接收到的声压最大，转换成的电信号也最强，此时发射器与接收器之间的距离应为半波长的整倍数。同时，在示波器上应观察到最强的接收信号。继续移动接收器时，信号将变弱，然后又再次出现强接收信号，相邻两次出现强信号的位置之间距离为$\lambda/2$，如图 15－1 所示。

2. 相位比较（行波）法

在波的传播方向上，两个相邻的振动状态完全相同的位置之间的距离为一个波长λ。通过观察图 15－2 所示的李萨茹图形（两个相互垂直的简谐振动的合成所得），判定同相点位置，或反向点位置，从而测得超声波的波长λ。由于斜线（相差为0°或180°的两束同频率正弦波所形成的李萨茹图形）位置比较容易确定，因此，这种方法比共振法更为准确。

四、实验内容与步骤

1. 仪器介绍

（1）超声声速测定仪由支架、游标尺及两只超声压电换能器组成。它们的相对位置的变化可以由游标尺直接读出，一只发射超声波，另一只接收超声波（见图 15－3）。

(2) 两只换能器的输入和输出插口，均为红色接信号，黑色接地（仪器外壳）。将发射换能器的输入端连接到函数信号发生器输出（OUTPUT）的T型BNC输出端，而使接收换能器的输出连接到二踪示波器的 Y_2（Y）输入端。示波器的工作方式选择波段开关置于 Y_2 挡，T/div、V/div 选择波段开关分别置于合适位置，例如 20μs 和 20mV 挡。

(3) 调节函数信号发生器的发射频率（功能键放在正弦波位置，频率倍频键放在100kHz挡），当示波器有接收信号显示之后，仔细调整信号发生器的输出信号频率，使发射换能器处于谐振状态。此时，示波器显示的接收信号的幅度最大，此时的共振频率，即为超声波频率 f。

2. 共振干涉法（驻波法）测波长

在换能器系统共振的条件下，从靠近发射换能器处，使接收换能器由近及远地移动。当示波器上出现较大振幅的信号时，利用游标尺上的细调机构，找到并记录产生最大共振信号的位置，逐点记下各振幅最大时的位置读数 X_1，X_2，…，X_{10}，X_{11}，X_{12}，…，X_{20}，然后利用逐差法处理数据，得到超声波的平均波长值 λ。

$$\overline{\lambda}_{共} = \frac{\sum_{i=1}^{10}(X_{10+i} - X_i)/10}{10} \times 2$$

3. 相位比较法（行波法）测波长

(1) 把函数信号发生器输出（OUTPUT）的T型接头的另一BNC输出端连接到双踪示波器的 Y_1（X）输入，使信号源输出的正弦波直接加到示波器 X 轴输入端，接收换能器输出接线位置不变。

(2) 在共振频率条件下，再将接收换能器平面端面调整到稍稍偏离垂直方向，以利于示波器观察合成图像。

(3) 用示波器观察李萨茹图形，使接收器由近及远移动，诸点记录当李萨茹图形由椭圆转化为向右（或左）的斜线时的接收器的位置 X_1，X_2，…，X_{10}，X_{11}，X_{12}，…，X_{20}，以逐差法求出超声波长的平均值 λ。注意：要求每个相邻测点的相差为 π。

$$\overline{\lambda}_{相} = \frac{\sum_{i=1}^{10}(X_{10+i} - X_i)/10}{10} \times 2$$

计算声速的不确定度时，应考虑仪器的误差，本实验用的声速测量仪卡尺，其允许误差限为0.02mm，信号发生器输出的频率允许误差限为0.2kHz。

注意：

(1) 实验时应首先确定压电换能器的谐振频率；

(2) 实验中，应随时调节示波器的 Y_2（Y）轴灵敏度步进旋钮，以提高测量灵敏度。

五、思考题

1. 为什么要在系统共振状态下测定声波的波长？

2. 本实验产生误差的主要原因是什么？

实验十七　声速测量

1. 共振干涉法(驻波法)测波长

单位:(cm)

波　节	位　置	波　节	位　置	波节差	位置差
X_1		X_{11}		$X_{11}-X_1$	
X_2		X_{12}		$X_{12}-X_2$	
X_3		X_{13}		$X_{13}-X_3$	
X_4		X_{14}		$X_{14}-X_4$	
X_5		X_{15}		$X_{15}-X_5$	
X_6		X_{16}		$X_{16}-X_6$	
X_7		X_{17}		$X_{17}-X_7$	
X_8		X_{18}		$X_{18}-X_8$	
X_9		X_{19}		$X_{19}-X_9$	
X_{10}		X_{20}		$X_{20}-X_{10}$	

2. 相位比较法(行波法)测波长

单位:(cm)

波　节	位　置	波　节	位　置	波节差	位置差
X_1		X_{11}		$X_{11}-X_1$	
X_2		X_{12}		$X_{12}-X_2$	
X_3		X_{13}		$X_{13}-X_3$	
X_4		X_{14}		$X_{14}-X_4$	
X_5		X_{15}		$X_{15}-X_5$	
X_6		X_{16}		$X_{16}-X_6$	
X_7		X_{17}		$X_{17}-X_7$	
X_8		X_{18}		$X_{18}-X_8$	
X_9		X_{19}		$X_{19}-X_9$	
X_{10}		X_{20}		$X_{20}-X_{10}$	

利用逐差法确定超声波的波长。

思考题