Lab 3: Speed of Sound in Solids

1 Introduction

In this experiment, we will make use of piezoelectric transducers (PZT) to generate and detect sound waves in several kinds of metal or plastic rods. A PZT is a special kind of ceramic that compresses or extends when a voltage is applied, or produces a voltage when it is compresses or extended. It's called a "transducer" because it "transduces" electrical signals into mechanical ones and vice versa. A stereo speaker is also a transducer. We will use two methods to measure the speed of sound:

1. Time-of-flight of sound pulses.

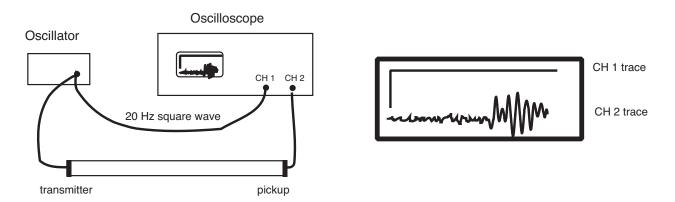2. Standing-wave frequency and wavelength measurements.

Figure 1: The left side of the figure shows the electrical connections for both parts of the experiment, and the right side shows a typical trace for the time of flight experiment.

The apparatus is pictured schematically in Fig. 1. For both methods, electrical signals in the form of various repetitive waveforms are produced by the oscillator and then are converted into mechanical vibrations by the PZT transducer attached to one end of the rod (labelled "transmitter"). The same signal is also displayed on channel 1 of the oscilloscope for reference, as shown and discussed below. In our experiment, the transducer is a disk made of barium titanate (chemical formula $BaTiO_3$). At the other end of the rod, an identical transducer ("pickup") converts the sound waves back into electrical waves, which can be observed on an oscilloscope.

2 Time-of-Flight Measurement

For this experiment we start with square waves because the transient at the switching point contains a wide range of frequencies (think Fourier transform) that propagate well in the various rods. The result is a short pulse of sound whose arrival time at the far end of the rod is readily determined. You should also try other waveforms that are available from the oscillator (some have triangle waves or pulse trains).

> **Question 1:** How is the transmitted pulse different for other waveforms. Describe what you see, and draw sketches.

Recall that an oscilloscope (scope) is merely a voltmeter that indicates the applied voltage by moving a small spot up and down, and at the same time, sweeps it across the screen so variation of the voltage are readily visible. If these variations (and the sweep) are faster than the response of the human eye (about 1/20 second) then it looks like a continuous trace that constitutes a graph of the time dependence of the voltage. What's important is that it is repetitive, and each sweep must lie directly over the previous ones or the image will look smeared, so the sweeps have to be synchronized with the repetition rate. This is implemented by "triggering" the sweep with some electrical signal, often the same one being observed. This is called "internal triggering".

Connect the oscillator output to one of the transducers and also, in parallel, to the channel 1 input of a dual-trace oscilloscope and set the scope to trigger internally on channel 1. Connect the transducer at the other end of the rod to the channel 2 input. Set the oscillator to produce a low-frequency (20 Hz or so) square wave, using the maximum amplitude the oscillator can produce. Observe the channel 1 signal on the scope, for example with the scope triggering on the rising edge of the square wave. You should also try other settings.

> **Question 2:** Why connect these in parallel? Why not connect them in series? Try series and see what happens.

Now connect the wires from the other PZT, on the far end of the rod, to channel 2 of the scope. You should be able to observe the signal generated by that PZT on channel 2 when the sound pulse arrives there. You may have to adjust the vertical sensitivity and sweep time (time base) so that you can see when the sound-wave disturbance reaches the pickup PZT. Remember you are still triggering the sweep off channel 1. Be sure you understand what you see, and how it can be used to determine the velocity of sound in the rod.

> **Question 3:** Besides the scope data, what else will you have to measure to determine the sound velocity? How will you get this information? Comment on the uncertainties on **ALL** the quantities you use to measure the sound velocity, and propagate them properly through your calculations.

3   Standing-Wave Measurement

For this part of the experiment we use sine waves instead of square waves. The sound waves travel along the rod and reflect back when they reach the end of the rod. At certain frequencies, stable standing-wave modes will be produced, generally resulting in an antinode at each end of the rod.

> **Question 4:** Explain why these reflections were not observed in the "time of flight" part of this experiment.

Such motion, of course, corresponds to the rod's normal modes of longitudinal motion. They look similar to the transverse ones in the sense that their wavelengths are half-integer multiples of the rod length, but the motion is along the rod, not transverse to it.

The pickup transducer attached to the oscilloscope serves as a detector for these waves. By studying the standing wave distributions, we will be able to determine the wavelength λ of each standing wave. By measuring the corresponding frequency ν with the frequency counter, the velocity of the sound wave can be determined.

Procedure: Once you have finished the time of flight measurement, change the waveform on the frequency generator to sinusoidal. Find the lowest resonant frequency by slowly tuning the frequency generator starting from a few hundred Hz to about 10 kHz. They are quite sharp, and some are easy to miss, so tune carefully and use plenty of 'scope sensitivity. You can tell there is a resonance, because the signal amplitude of the pickup transducer changes drastically, and the rod emits a characteristic buzzing sound. Because we've got antinodes for the pressure wave at both ends of the rod, the length of the rod corresponds to one wavelength at this lowest resonance frequency. From this frequency, the speed of sound can be calculated as: $v = L \cdot \nu$ where ν is the lowest resonance frequency and L is the rod length. Try to find other resonances by tuning the frequency; are they following each other in order or not? If yes, can you figure out what the corresponding wavelength is? If not, can you guess why? (How would you expect it to be?)

Determine the wavelength and frequency for as many different standing-wave modes as you can observe. From this data, how will you determine the sound velocity? Study as many samples as time permits, by exchanging places with other groups. Aluminum, copper, steel, brass and plastic should be available. You can check your answers on the web using Google, but be sure to cite your sources.

4   A Brief Word on Theory

According to theory, the sound velocity vs extensional (longitudinal) waves in thin rods is $v_s = \sqrt{Y/\rho}$, where Y is Young's modulus and ρ is the density of the sample. Look these up in an appropriate reference and see if they give values that agree with your measurements, and comment on any discrepancies. Be sure you include your discussion of measurement uncertainties.