Experiment 220: Speed of Sound in Water

Aims

The aim of this experiment is to measure the speed of sound in hot water, cold water and sea water.

Method

The speed of sound in water is measured in this experiment by finding the return time of an ultrasonic pulse reflected off the surface of a column of water. By varying the height of the water column an accurate value of the pulse speed can be found.

A specialised ultrasonic pulse generator is used in this experiment. The pulses are generated from a transducer at the base of the column. The transducer is a disc of ceramic material which is piezo-electric i.e. when it is squeezed a voltage is generated. The effect also works in reverse and if a voltage is applied the material stretches or shrinks. A pulse is sent to the transducer which transmits it into the water as a pressure pulse. The transducer also acts as a receiver and converts the received pressure pulse into a voltage signal. In this way, the transducer acts as both transmitter and receiver of the ultrasonic pulses.

An oscilloscope is used to observe the transmitted and reflected pulses.

The column can be filled with either hot or cold water from the sink taps. A pump is required to fill the column with sea water from one of the storage containers.

Never leave the water column filling unattended.

Procedure

Travel Time Measurements

(1) To remove any dust or other contaminants, first flush the column out with cold water. To do this, *first ensure the salt water drain/fill valve is closed* (handle perpendicular to pipe). Then fill the column to the highest level mark with cold water from the sink tap. Then empty the column to the fresh water drain.

(2) Fill the column to the highest marked level with cold water. Ensure that the sink tap and column valves are fully closed. Turn on the digital oscilloscope and the pulse generator. Set the oscilloscope as follows:

Vertical mode: CH1	Volts/div: 50 mV
Trigger source: CH1	Time/div: 0.5 ms

You should see a fast varying signal triggering the oscilloscope, followed by one or more smaller signals (see Figure 2). The first, large amplitude signal, is the residual ringing of the transducer plate following the pulse transmission. The smaller signals are reflections off the surface of the water column. Ask a demonstrator for help on the oscilloscope if you are unable to see the signals. Note that when the column is first filled with water the water contains many tiny bubbles. These bubbles absorb the sound so no reflected pulse appears until the bubbles drift to the surface and disappear.

The reflected pulse is a superposition of many copies of the transmitted pulse. The first part of the reflected pulse has travelled directly to the surface and back again. Later parts of the reflected pulse have reflected once or several times from the sides of the column on their way up and down. These different paths interfere and the full shape of the reflected signal changes as the water depth changes. However, the first part of the signal is the direct path and can be used for measurements of travel time.

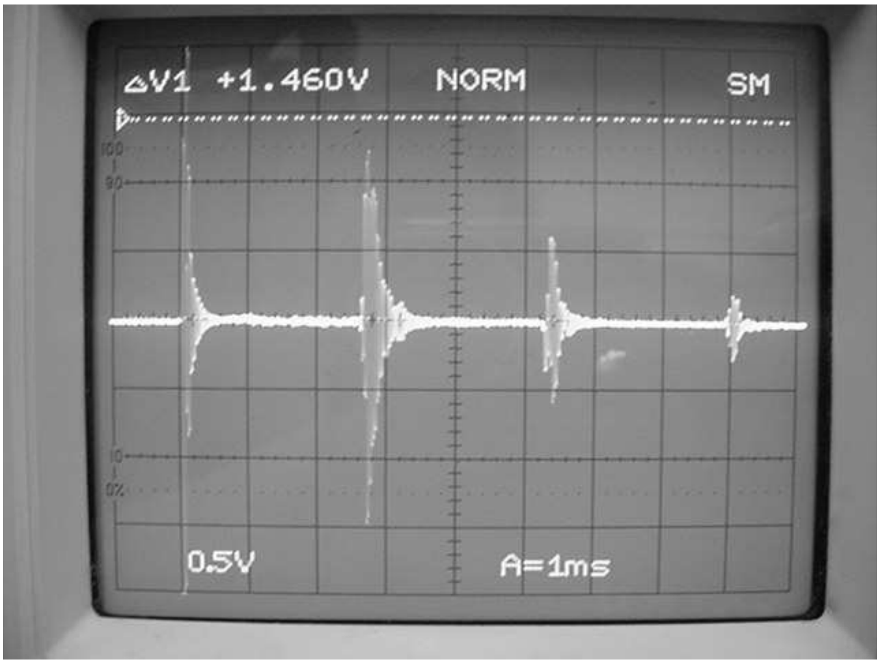

Figure 1: Example of oscilloscope output. The large signal on the extreme left is the residual oscillations of the transducer crystal. Three reflected signals are visible on this example.

(3) Measure the time between the transmitted pulse and as many reflected pulses as possible for the water column. You should use the time axis cursors on the oscilloscope to ensure an accurate reading. Use the SELECTOR control to select ΔTA ms. Use the CURSORS control to highlight the first cursor (a small triangle marker shows at the top of the cursor line) and the VARIABLES control to set it at the start of the transmit pulse. Then highlight the second cursor and set it on the start of the reflected pulse. The travel time for the reflected pulse is then shown as ΔTA ms.

Ask a demonstrator if you are unsure how to use the oscilloscope cursors.

(4) Repeat the time measurements for several water column depths by dropping the water level in stages. The reflected signals start to become superimposed on the transducer ring signal at lower water column depths. It is advisable not to use these arrival times in the calculation of the sound velocity. However, you can use later reflected pulse arrival times. It is also advisable not to use water column depths of less than about 0.7 metres. **Measure the temperature of the water several times throughout the experiment and record the values.**

(5) Completely drain the column of cold water and repeat the above procedures for hot water.

(6) Using the pump provided, fill the water column with salt water from the storage container underneath the sink. There should be enough salt water to give you a head of 1.85 m. Ask the lab technician to refill it if needed. Repeat Procedure 4. Ensure that you drain the sea water back into the storage container *and leave the apparatus with the salt water drain/fill valve closed.* If you contaminate the salt water with fresh water, tell the lab technician so he can replace the water.

Transducer measurements

(7) Select HOLD and change the TIME/DIV and VOLTS/DIV settings to display the ringing part of the transmit signal. It should look like smooth exponentially decaying oscillations. Measure the period of the ringing oscillations and calculate the frequency.

(8) The exponentially decaying oscillations are described by:

$$A(t) = A(0)\exp\left(\frac{-t}{\tau}\right)$$

(i) Measure the amplitude of the oscillations at suitable places and find the time constant τ for the oscillations. (ii) If the time constant of a resonant system divided by the period is a number n then the Q-factor for the system is given by $Q = n\pi$. Estimate the Q factor for the transducer.

Results

(9) Plot a graph of travel time against distance using your data for hot, cold and sea water.

(10) Find the speed of sound in each case with an estimate of the standard error.

The standard error can be found as follows assuming you have a set of distances d_i and times t_i for $i = 1, 2, ...N$.

Use Python to create a script file which includes the following steps:

(a) Define arrays `d` and `t` containing the data.

(b) Fit the data with a straight line using the `polyfit` function (from the `numpy` module). This calculates the parameters `p` in `t = p[0]*d + p[1]`. The fitted times t_f are given by `tf = polyval(p,d)`.

(c) Find σ_t, the estimated root-mean-square error in each travel time as

$$\sigma_t = \sqrt{\sum\left(\frac{(t - t_f)^2}{N - 2}\right)}$$

The N-2 provides a best estimate because two parameters have been fitted.

(d) Now repeat the straight line fit and obtain the error estimates using `p,sp = regress(d,t,sigmat,1)`. The parameter `p[0]` is related to the speed of sound.

(11) A standard expression for the speed of sound in water is:

$$c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.01T)(S - 35) + 0.016Z$$

where
T = Temperature deg C
S = Salinity in parts per thousand. $S = 0$ for fresh water, $S = 35$ for sea water.
Z = Depth in meters below water surface.

Compare your experimental results with the standard expression and comment on any discrepancies.

(12) List the resonant frequency of the oscillator, its time constant and its Q-factor.

List of Equipment

1. Oscilloscope
2. Ultra-sonic pulse transducer driver
3. Thermometer
4. Tank of sea water

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Revised: R. Au-Yeung, February 17, 2014

Appendix – regress

```
import numpy as np
import scipy.linalg as sl

def regress(x,y,sy,n):
    A = np.ones(len(x))
    for i in range(n):
        A = np.column_stack((x**(i+1),A))
    W = np.zeros((len(x), len(x)))
    for i in range(len(x)):
        W[i,i] = 1 / (sy[i]*sy[i])
    Ap = A.T
    b = np.dot(np.dot(Ap,W), A)
    bi = sl.inv(b)
    c = np.dot(Ap, np.dot(W,y))
    p = np.dot(bi, c)
    sp = np.diagonal(bi)
    return p,sp
```