Experiment 2A: Speed of Sound using Kundt's tube

Apparatus: Audio frequency generator, cathode ray oscilloscope (CRO), head-phones, Kundt's tube apparatus, BNC ((Bayonet Neill–Concelman) connector for Kundt's tube to oscilloscope in order to visualize the signal.

Aim: To find the speed of sound using the relation $v = \nu\lambda$ where ν is the frequency of sound waves from the audio frequency generator and λ is the wave length of sound waves inside Kundt's tube. Determine λ by (a) measuring the locations of nodes of standing waves produced inside Kundt's tube, and (b) by use of Lissajous patterns seen on CRO screen.

Basic Idea: The basic idea behind this experiment is to generate sound waves of known frequency inside the Kundt's tube apparatus and find the locations of nodes. Distance between two consecutive nodes being $\lambda/2$ we can obtain wavelength this way and hence the velocity of sound. We can find the locations of nodes as we scan the length of the vibrating air column using a microphone. At locations of nodes, the sound picked up by the microphone would almost drop to zero. We can also visualize the variations of signal by simultaneously connecting the output of the microphone to the Y- channel of CRO.

Theory behind the experiment: Sound waves generated by audio frequency generator are fed to the Kundt's tube from one end via a speaker. The movable piston at the other end serves as the reflecting wall. Standing waves may be generated between the speaker at one end and the piston wall at the other end. Since the piston is movable, the effective length of the tube in which standing waves are generated can be adjusted. The situation here is slightly different from the standing waves generated on a stretched string whose two ends are rigid and hence positions of nodes. Instead, here we have a medium (air in the tube) that is constantly driven by the driving frequency from the audio frequency generator. So, like a driven oscillator that oscillates at the frequency of the driving force, these are driven waves in a tube that have the frequency of the audio oscillator. For standing waves on a string with nodes at its two ends, there is a relation between the length of the string and wavelength of the waves on the string. If the string length is an integral multiple of half wavelengths, then it is vibrating in one of the normal modes. Alternatively its general vibration is a linear superposition of all possible normal modes. What we have here is a system of waves in a tube that are constantly driven by an audio frequency generator. Therefore steady-state solutions are stationary waves with alternating nodes and antinodes, irrespective of the frequency and the length of the air column, subject only to the boundary conditions-- at the wall the amplitude is always zero and the speaker end is oscillating with $a\cos\omega t$. In the steady state, the wave equation is given as:

$$\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$$

Here v is speed of sound waves in air and $y(x,t)$ is the amplitude of longitudinal oscillations of air at location x at time t. Using the method of separation of variables, we can write:

$$y(x,t) = f(x)\cos\omega t$$

Our boundary conditions are:

$y(0,t) = 0 \quad y(L,t) = a\cos\omega t$ implying $f(0) = 0 \quad f(L) = a$. Upon substituting $y(x,t)$ in wave equation we have:

$$\frac{\partial^2 f(x)}{\partial x^2} + \frac{\omega^2}{v^2} f(x) = 0.$$

The general solution is given as:

$$f(x) = A\cos\frac{\omega}{v}x + B\sin\frac{\omega}{v}x.$$

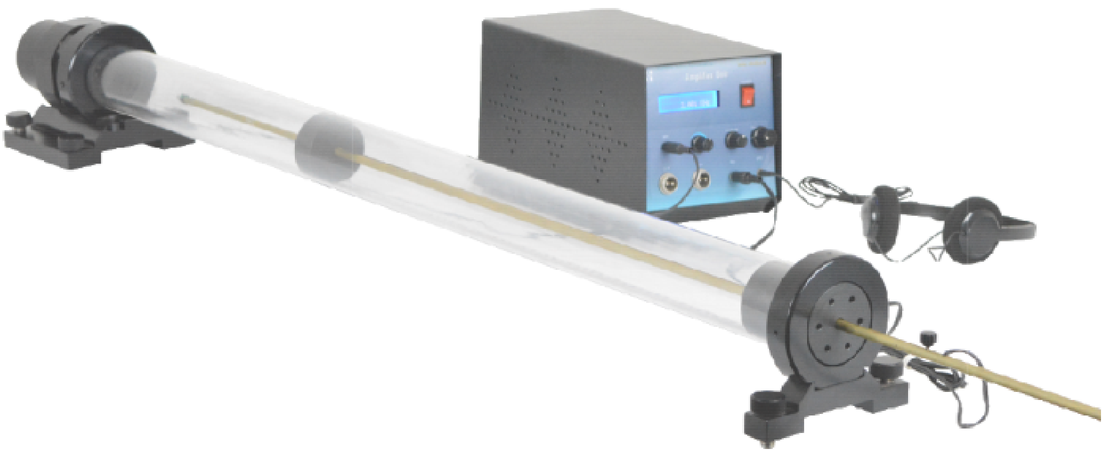
From the boundary conditions we find that $A = 0 \quad B = \dfrac{a}{\sin\frac{\omega}{v}L}$.

Thus, our steady state solution is,

$$y(x,t) = \frac{a}{\sin\frac{\omega}{v}L}\left(\sin\frac{\omega}{v}x\right)\cos\omega t.$$

For positions of nodes we must have $\dfrac{\omega}{v}x = n\pi, \quad n = 0, 1, 2, 3...$

Set up and procedure:



Velocity of sound from locations of nodes

1. The arrangement of Kundt's tube along with audio frequency generator and head phone is shown in figure. To this we may also connect CRO to the BNC connectors shown in the audio frequency generator for better visualization of the output.
2. The output of the audio frequency generator is fed to the speaker at one end of the Kundt's tube. The piston at the other end serves as a wall. The thin metal rod coming out of the piston is the microphone and its position can be adjusted with a small lever on the rod outside the tube. By connecting the head-phones, the output of the microphone can be heard using the head-phones. Connecting the head-phone also ensures that the loud sound from the speaker does not disturb others. Using BNC connector we can also send the output of audio frequency generator to the X-channel of CRO for visualization.
3. The distance between the speaker at one end and the piston (and the micro phone) at the other end should be more than 50 cm in order to accommodate measurement of many nodes.

Once you fix the distance of the piston wall, note it down and ensure that this remains constant throughout the experiment. Also connect the output of microphone to the Y-channel of CRO for visualization of nodes and antinodes.

4. Now choose a frequency of 2KHz and slowly scan the length of air column by gently pushing the microphone lever while ensuring that you do not move the piston wall. Whenever you see the signal of the Y-channel (to which output of microphone is connected) dropping to its minimum value (it will be very close to zero but never exactly zero as boundary conditions are far from ideal), note down the location of the microphone. Find all the positions of nodes until you reach the other end.
5. Average distance between two consecutive nodes would give you $\lambda/2$ and from this you can obtain the speed of sound using the frequency of the audio generator.
6. Repeat the experiment with 3KHz and 4KHz.