The Water Bottle Resonator

Winter 2021, University of Waterloo

Learning Objectives

In this project, you will apply your knowledge of acoustic phenomenon to a water bottle Helmholtz resonator. The main topics that will be applied are 1D vibration & oscillation, radiation, cavities & pipes, microphones, and Helmholtz resonators. The main tasks will be to use a water bottle to 1) find the speed of sound in air, 2) test the end correction for an unflanged pipe, and 3) find the Q value for an unflanged pipe.

Project Description

As we have learned in the course, a cavity with one open end can modeled as a Helmholtz resonator. By blowing into the cavity, we generate a wide range of frequencies in our pressure wave, but our bottle will amplify its resonance frequency when driven with these frequencies.

In part A, you will perform tasks 1) and 2). By finding the resonance frequency and physical measurements of the bottle, we can indirectly measure the speed of sound in air. We can also use the relationship between these measure quantities to test our prediction for end correction in an unflanged pipe. That is, the additional height of fluid loaded to our system.

In part B, you will perform task 3). After finding the resonance frequency, we can drive the system at that frequency using a speaker. We can compare the volume of this tone before and after we put the resonator under the speaker to find the amplification factor Q.

Below are recommended tools and task breakdown to achieve this goal. You may make substitutions to the equipment or modifications to the steps given the tools you have available to you. Ensure any modifications you make enables you to submit all that is required in the list of deliverables.

Equipment and Software

- Water bottle with removable lid
  - Assume it is a 1-D tube with one end close and the other end open and unflanged
  - Preferable use a cylindrical bottle to closely approximate a 1-D tube
- Tap water to fill bottle
- Ruler
- Frequency/Decibel measuring device (ex. *dB Meter* app for iPhone/Android)
- Small external speaker (ex. Bluetooth speaker, or a second device)
- Tone generator website (ex. https://www.szynalski.com/tone-generator/)
- Coding program (ex. Python or MATLAB)

Task Breakdown

Part A	1	Remove lid and fill a water bottle three quarters full
	2	Record diameter across opening
	3	Open dB / Spectrum app
	4	Blow into opening
	5	Record resonated frequency using app, and water level with ruler
	6	Empty some water
	7	Repeat steps 4-6 four more times
	8	Calculate period of oscillation given the frequency
	9	Using least squares method, find the "slope" and "y-intercept" between period vs height
	10	Create a scatter plot of the data with the line of best fit
	11	Derive an expression for the slope as a function of the speed of sound "c"
	12	Use this expression to estimate the speed of sound
	13	Derive an expression for the intercept as a function of the radius
	14	Use the observed intercept and measured radius to calculate the end correction
Part B	1	Remove lid and ensure the water bottle is empty
	2	Measure full height and diameter of water bottle using the ruler
	3	Open tone generator website and test the speaker can play a tone on demand
	4	Open dB / Spectrum app in phone
	5	Blow into water bottle and find this resonant frequency using the spectrum app
	6	Set the frequency on the tone generator to this resonance frequency
	7	Play the tone and a comfortable volume
	8	Hold the phone and speaker together as one unit, with the speaker pointing down
	9	Move unit far from the water bottle and record the dB level
	10	Move unit directly above water bottle and record the dB level
	11	Using the measured height and diameter, calculate the expected Q at resonance (Hint: see chapter 10.3 in Kinsler)
	12	Convert the measured dB levels to (peak) pressure amplitudes. Use 20μPa (effective pressure) as the reference.
	13	Calculate the amplification factor Q given the observed pressure amplitudes
	14	Calculate percent error between the theoretical model and observed amplification factor

List of Deliverables

Please include the following information in your final submission.

- Table of all length, frequency, SPL level measurements
- Equations used
    - Include derivations to expressions derived
    - Include citations to equations not derived
- Plot of data with line of best fit, legend, axis, and title
- Typed/written discussion answering the following questions
    - What was your calculated values? How does this compare to the known/theoretical values and what is their percent error?
    - Did you have to make any modifications to the experiment and why?
    - What are possible reasons your result may not match the known/theoretical values of the quantities estimated? Think of what assumptions were made in the equations used.
- List of any references used, including course material
- Copy of your code

References

Kinsler, L. E. (2000). Fundamentals of acoustics (4th ed.). Wiley.
Müller, G., & Möser, M. (Eds.). (2013). Handbook of Engineering Acoustics. Springer-Verlag.