Vm495 Lab Report

Lab 2: Research on Force Production by Sound Energy

Group 2E

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[Abstract]

It is common knowledge that sound wave contains the kinetic energy. In this experiment, we designed a method to measure the propulsive forces caused by sound waves on the resonators. A Helmholtz Resonator was built and an encoder connected with LabView program was used to measure the angular displacement. Eventually, we processed the data from LabView and found the relationship between the forces and the features of different resonators.

Table of Content

I. Nomenclature

F	=	frequency (Hz)
t	=	time (s)
S	=	position (mm)
v	=	velocity (mm/s)
a	=	acceleration (mm/s^2)
L	=	neck length (mm)
D	=	neck diameter (mm)
V	=	volume of the resonator (mL)

II. Objective

Our objective is to build a Helmholtz Resonator to do research on the process of the acoustic energy transmitting to kinetic energy. We will use LabView to record the propulsive forces of different resonators caused by different frequency of sound waves on the resonator and try to find the relationship between the sound waves, the resonators' features and the propulsive forces.

III. Introduction and Background

Sound is a vibration that typically spreads as a wave of pressure through a transmission medium. Sound contains energy and the type of energy in vibration is kinetic energy. The factors effect a sound wave produced by a fixed speaker is frequency and amplitude, which is also the factors influencing the energy spread by sound. We use the the Helmholtz resonator experiment to observe the phenomena caused by sound energy and analyze the factors governing the sound-energy relationship. [2]

As shown in Figure 3.1, the resonator is a container with a port. In this experiment, we use different drink bottles as resonators. The resonator stores air in its internal space, measured as cavity volume and the port allows air to flow out. Every resonator has its resonance frequency and sound wave transfers the greatest energy to the resonator when as this frequency. When sound wave causes resonance of the resonator, the air inside vibrates and it flows out from the port like a jet, which gives a propulsion force to the resonator. [2]

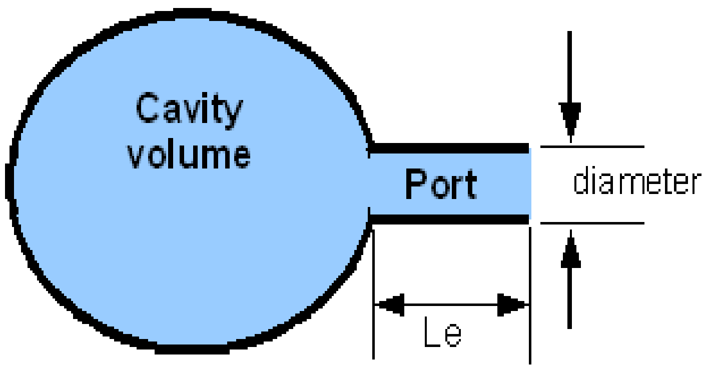


Figure 3.1. Helmholtz resonator.

To find the resonance frequency of the resonators, we use the hitting method. We hit the resonator by hand and record the voice the resonator generators, then we analyze the sound wave figure after FFT transfer to find resonance frequency. The example result shown in Figure 3.2 shows the reflect sound wave of one resonator. Lt has a maximum amplitude at 270Hz, which is defined as resonance frequency.

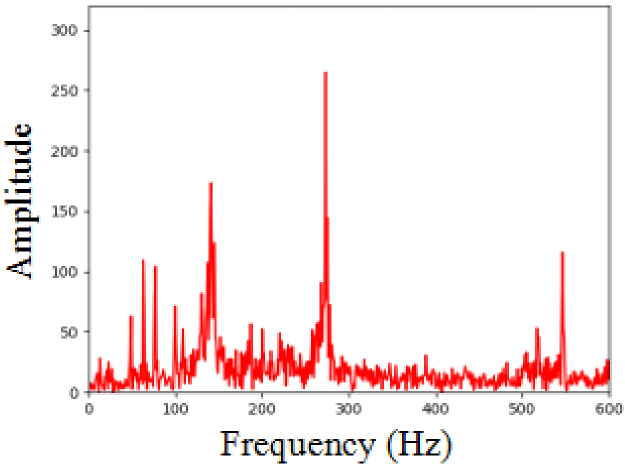


Figure 3.2. Sound wave data after FFT.

The force caused by resonators is very small because of the low efficiency of sound-energy transfer. To measure the sound-energy relationship, we use two resonators fixed on two ends of a bar with their port pointing to the same rotation direction. The speaker under the structure generators resonance sound wave causing the resonators to generate propulsion force. The bar then rotates and from its acceleration and angular speed, we can calculate the kinetic energy and then analyze the factors of energy transferred by sound wave.

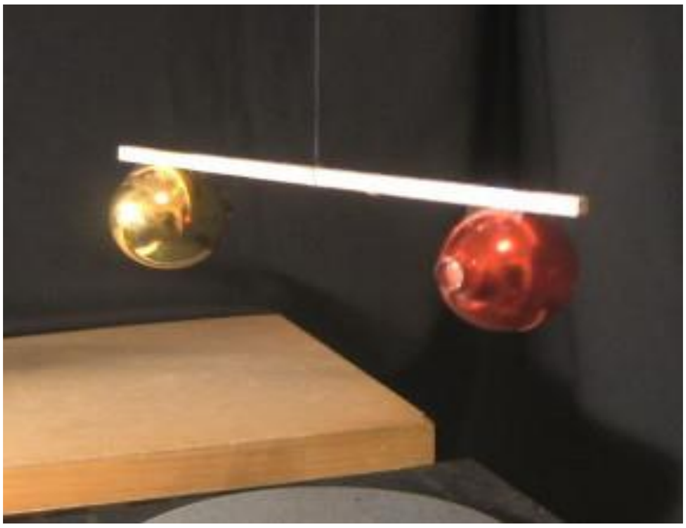


Figure 3.3. Helmholtz resonator experiment.

IV. Experimental Method

A. Equipment & Sensor

Table 4.1. The table of equipment and sensors used in the experiment.

Name	Type	Quantity	Usage
Yibao mineral water bottle	350 mL	2	Resonator
Yibao mineral water bottle without half of the neck	350 mL	2	Resonator
Coke Zero bottle without half of the neck	500 mL	2	Resonator
Victory vitamin water bottle	500 mL	2	Resonator
DAQ	X Series	1	Acquiring data
Encoder	E6B2-CWZ6C	1	Recording displacement
Circuit board	/	1	Measuring voltage
Acrylic bar	320*20*4mm	1	Holding resonator
Computer	Dell	1	LabVIEW
Power supply	0-120V	1	Supplying power
Push-pull electromagnet	ZYE1-1038DC 12V	1	Providing initial velocity
Aluminum alloy frame	4040	1	Supporting push-pull electromagnet
Acrylic plate	3mm thickness	4	Sound insulation
Plastic box	3mm thickness	1	Sound insulation
Speaker	HIRALIY A8	1	Playing audio

Table 4.2. The table of specification and range of instruments.[3]

Name	Specification and range	
Yibao mineral water bottle	Volume	350 mL
	Neck length	17.53 mm
	Neck diameter	21.34 mm
Yibao mineral water bottle without half of the neck	Volume	350 mL
	Neck length	2.00 mm
	Neck diameter	31.00 mm
Coke Zero bottle	Volume	500 mL
	Neck length	17.53 mm
	Neck diameter	21.34 mm
Victory vitamin water bottle	Volume	500 mL
	Neck length	17.53 mm
	Neck diameter	31.00 mm
Encoder (E6B2-CWZ6C)	Resolution ratio	1000 pulse/ rotate
	Axial maximum force	20 N
	Radial maximum force	30 N
Acrylic bar	Size	320.00*20.00*4.00mm
Push-pull electromagnet	Force	25 N

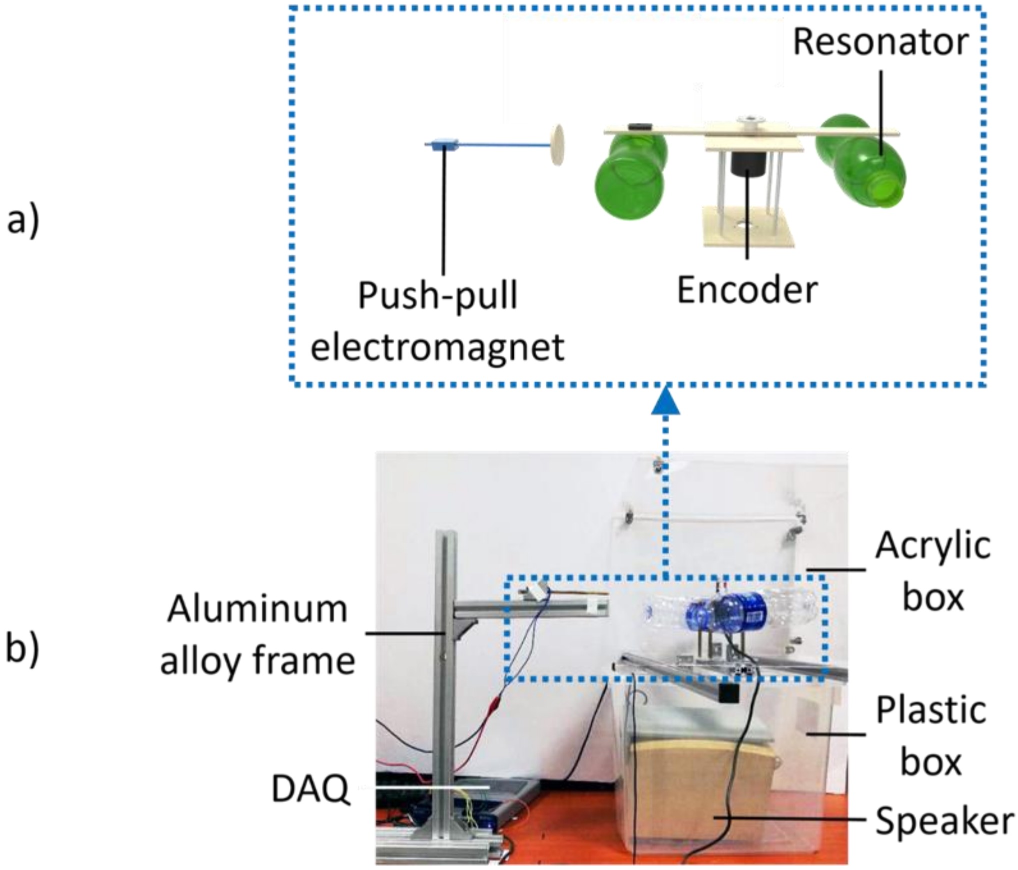


Figure 4.1. a) Detailed model of the main setup, b) Experiment setup.

B. Test Procedure

Experiment preparation

1. Cut acrylic board

Cut an acrylic board to get a 320*20*4mm acrylic bar, three holding parts by a laser cutter. The CAD diagram of the bar and holding parts is shown in Figure 4.2.

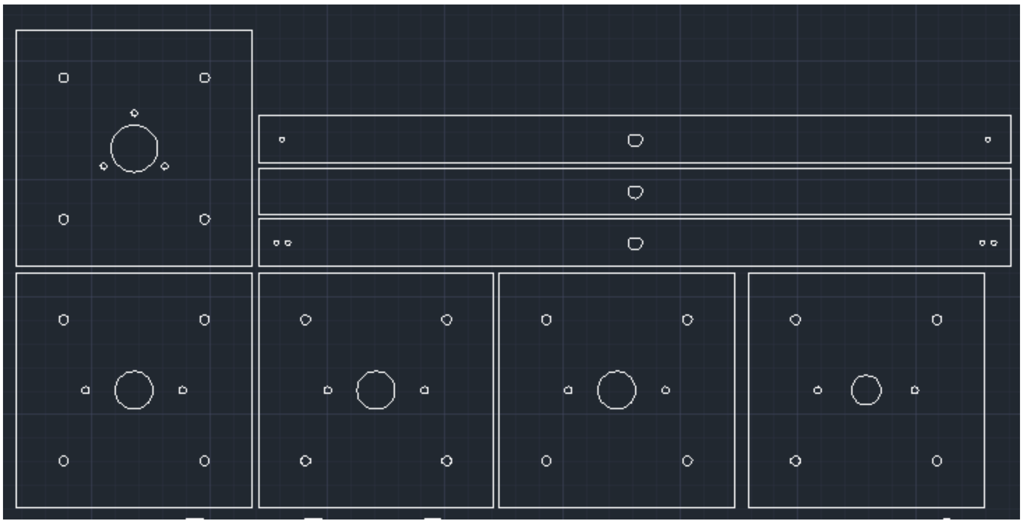


Figure 4.2. CAD diagram of the acrylic bar and holding parts.

2. Fix encoder, acrylic bar, bottle and push-pull electromagnet

Connect the acrylic holding part with 4 mm copper cylinders to make a support frame for the encoder. Also construct an aluminum alloy frame for the push-pull electromagnet. As shown in Figure 4.1, fix the encoder on the support frame, and then fix the acrylic bar on the encoder. Next, fix the bottle (resonator) on the acrylic bar. In addition, fix the push-pull electromagnet on the aluminum alloy frame.

3. Insulate sound

As shown in Figure 4.1, put the speaker into a plastic box under the support frame and then place an acrylic box on the top of the frame to insulate sound.

4. Connect circuit

Build a circuit for dealing with the signal from the encoder and transferring voltage signal from the encoder to DAQ.

5. DAQ connection and LabVIEW programing

Create a new program in LabVIEW and then add a data acquiring output for the encoder. Next, connect the circuit output to DAQ and adjust LabVIEW program so that we can collect appropriate set of data in one second.

First Experiment

6. Record sound

Hit the bottles used as resonator and record the sound that resonators generate.

7. Analyze resonate frequency

Analyze the voice amplitude in Python to find the peak amplitude and its frequency as the resonate frequency.

Second Experiment

8. Do experiment without sound

Use the push-pull electromagnet to give the resonators an initial angular speed, and record the performance by the encoder.

9. Do experiment with sound

Open the speaker and play a sound with resonate frequency generated by Python. Repeat the process 8 for the same resonator.

10. Repeat process

Repeat process 8 and 9 for all four kinds of bottles (resonators).

C. Calibration Method

Thanks to the inbuilt calibration function inside the LabVIEW software, the encoder can be calibrated automatically. As a result, we do not need to calibrate the result again.

V. Results

Based on the Taguchi design we did 4 group of tests, which is shown in Table 5.1.

Table 5.1 Taguchi design.

Run	Neck length	Volume	Neck cross section
1	+	-	-
2	-	-	+
3	-	+	-
4	+	+	+

We made several assumptions to carry out the experiments.

1. We are using light resonators; mass of resonators can be ignored in the system.
2. Drag force produced by air during the rotation can be ignored.

In the 1st run, we use 'Yibao' bottle with a volume of 330ml, neck length of 17.53 mm, neck cross section of 21.34mm.

In the 2nd run, we use 'Chapai' bottle with a volume of 330ml, cut its length to get a neck length of 2mm, neck diameter of 31mm.

In the 3rd run, we use 'Zero cola' bottle with a volume of 500ml, neck length of 17.53mm, neck diameter of 21.34mm.

In the 4th run, we use 'Vita water' bottle with a volume of 500ml, neck length of 17.53mm, neck diameter of 31mm.

With the 4 tests, we can form a Taguchi test for the parameters neck length, volume, neck cross section.

For each resonator, we need to find its resonate frequency first.

To find the resonate frequency, we first knock the resonator by hand and record the voice.

Do FFT analysis to the recorded acoustic data, we can find the resonate frequency.

Figure 5.1 shows the corresponding frequency of ‘zero cola’.

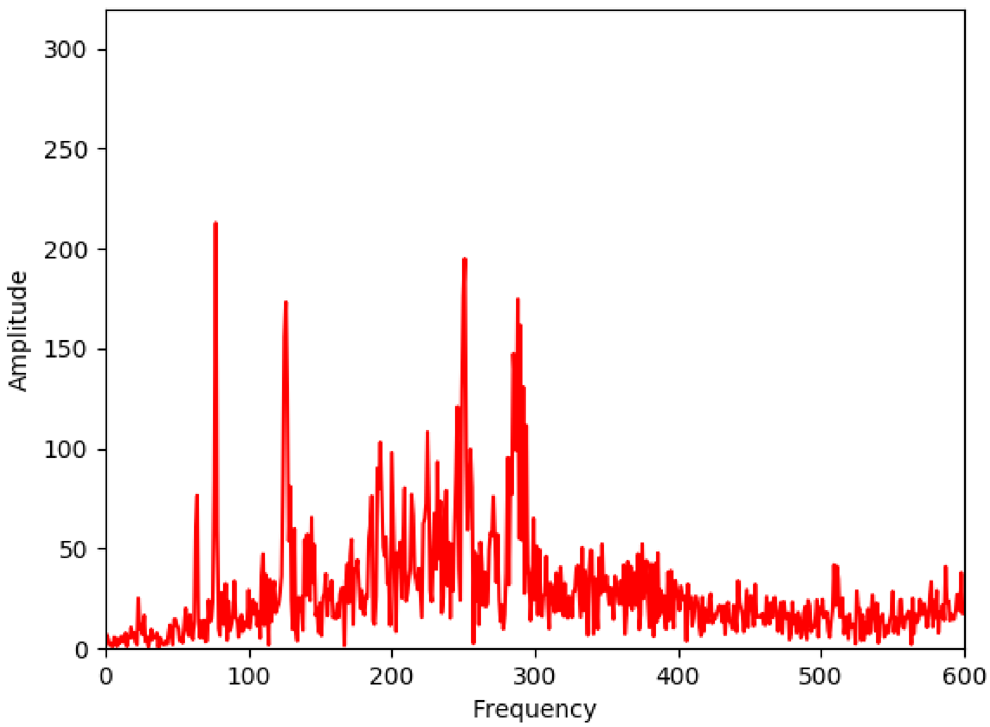


Figure 5.1 Frequency analysis of ‘zero cola’.

Note that we sample the acoustic data at a frequency of 44100 Hz. And the measured frequency is about 200Hz, so there will not be a risk of aliasing.

The corresponding frequency for each resonator is shown in table 6.1

Table 6.1 Resonate frequency for each resonator

	1	2	3	4
Frequency(Hz)	230	210	250	235

We use encoder to record the angle of the system both with sound and without sound, then we compare the behavior of the two system and find the acceleration provided by resonators.

Denote position as the length the **resonator** has passed through, namely,

Position=Angular position*radius of experiment setup

We show raw data for 3rd run as an example:

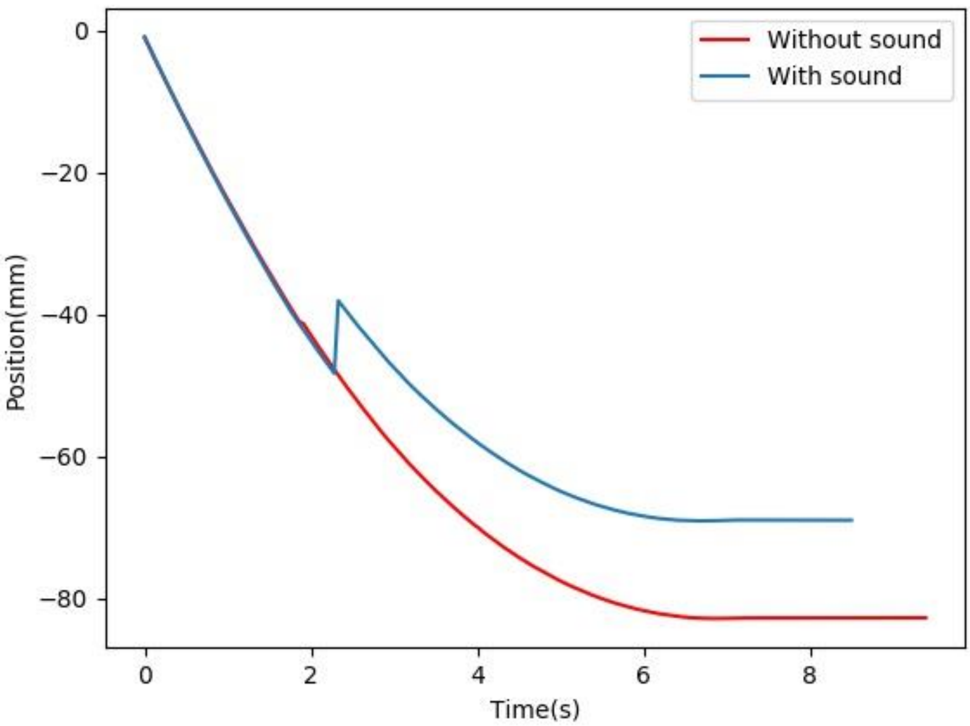


Figure 5.2 Time-Position plot for 3rd Run

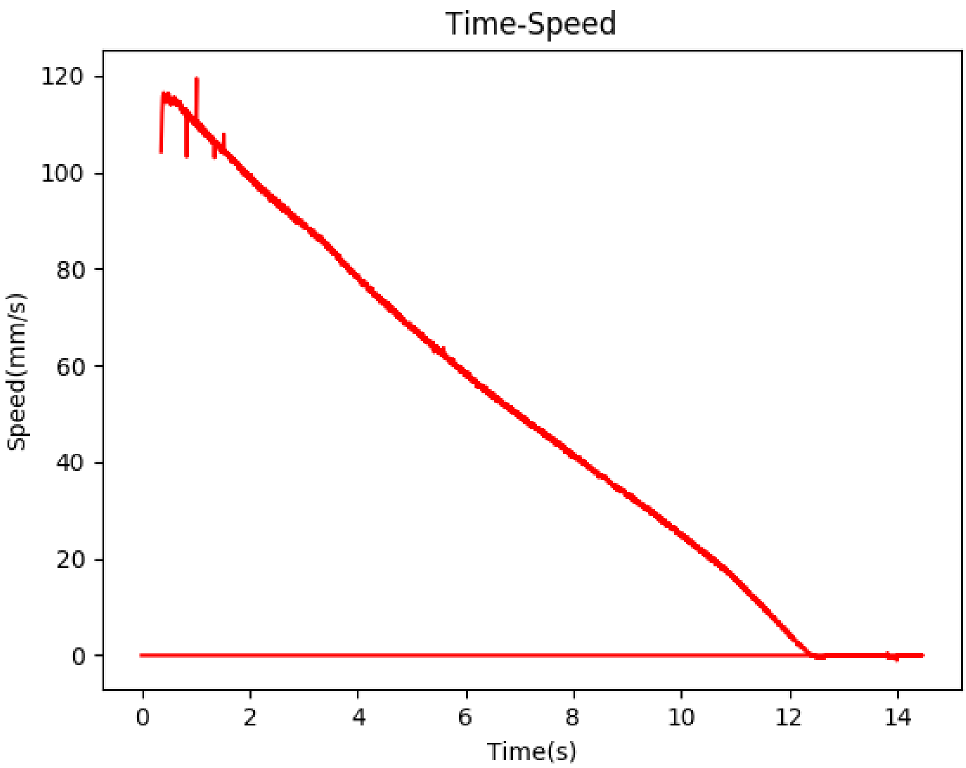


Figure 5.3 Time-Speed plot for 3rd Run (without sound)

Figure 5.2 shows the time-position data; Figure 5.3 shows the time-speed data.

It is actually made of some very step, which is not the actual result we hope to get. Also, there exists a line indicating a series of 0 velocities. This line exists here because we are using a encoder with poor resolution. Sometimes it will record same data as time pass by. In this case we will calculate speed as 0.

If we differentiate this data to find acceleration, we will get a set of data composed of lots of impulses, instead of continuous acceleration.

The result of direct differentiation is shown in Figure 5.4. (Experiment without sound)

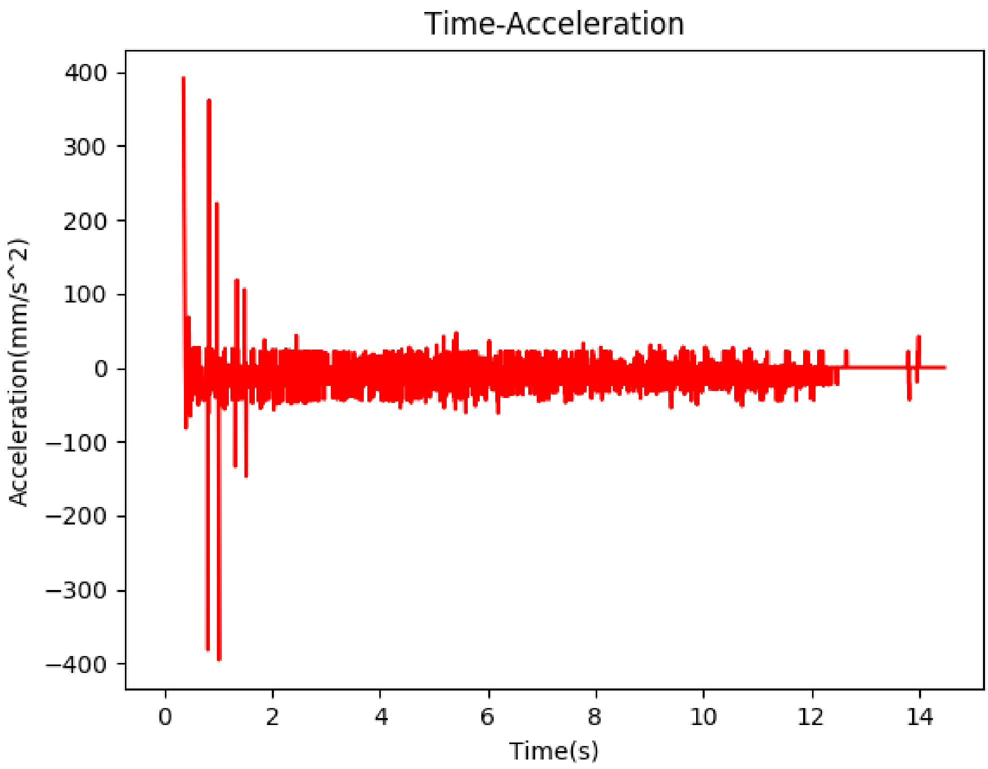


Figure 5.4 Direct differentiation from speed data

We see that due to the limitation of encoder's resolution, we obtain poor results. In order to get the acceleration correctly, we tried to fit the speed data into a line by a polynomial approximation. Then we can obtain the acceleration by differentiate the approximation function. In this experiment, we have no idea about the position-time relation in advance, for the sake of safety, we use a 5th order polynomial to fit the position data. Comparison between fitted data and original data is shown in Figure 5.5 (take the trial without resonators resonating as an example).

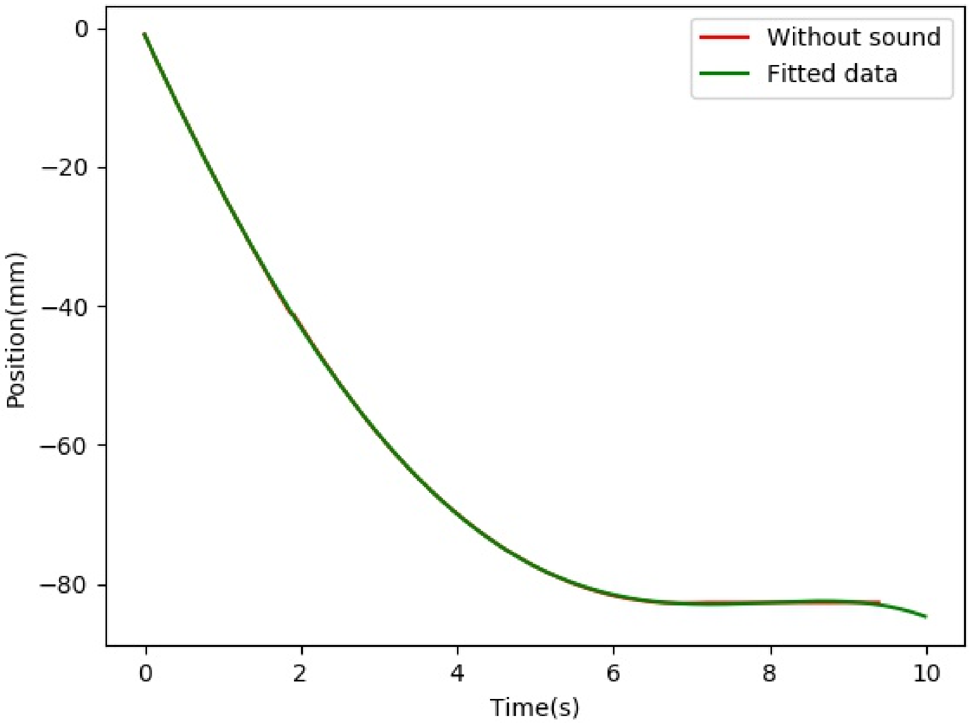


Figure 5.5 Comparison between fitted data and original data.

We then calculate the second derivative, and we take average on the second derivative as the final acceleration which is shown in Table 5.2.

Table 5.2 Final acceleration.

	1	2	3	4
Acceleration(mm/s^2)	8.24	1.035	23.48	-1.10

By plotting the mean of each parameter, we get:

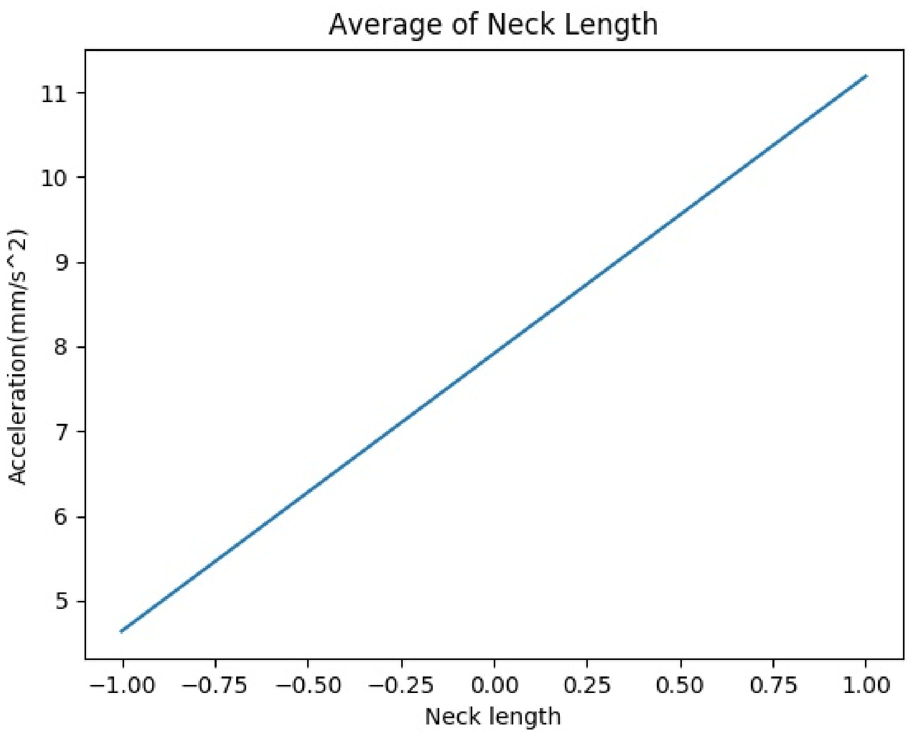


Figure 5.6. Average acceleration of neck length.

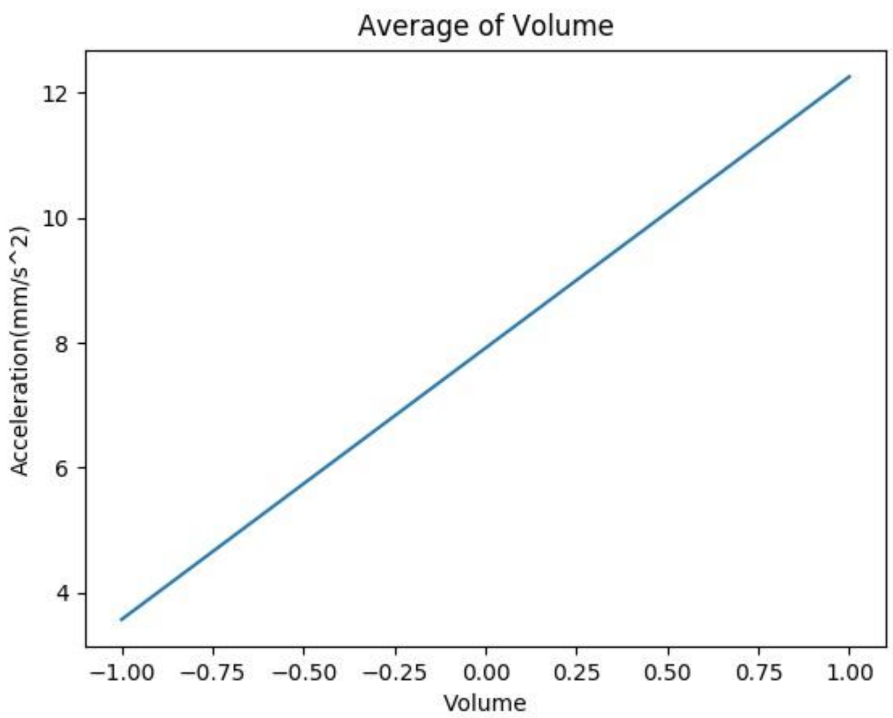


Figure 5.7. Average acceleration of volume.

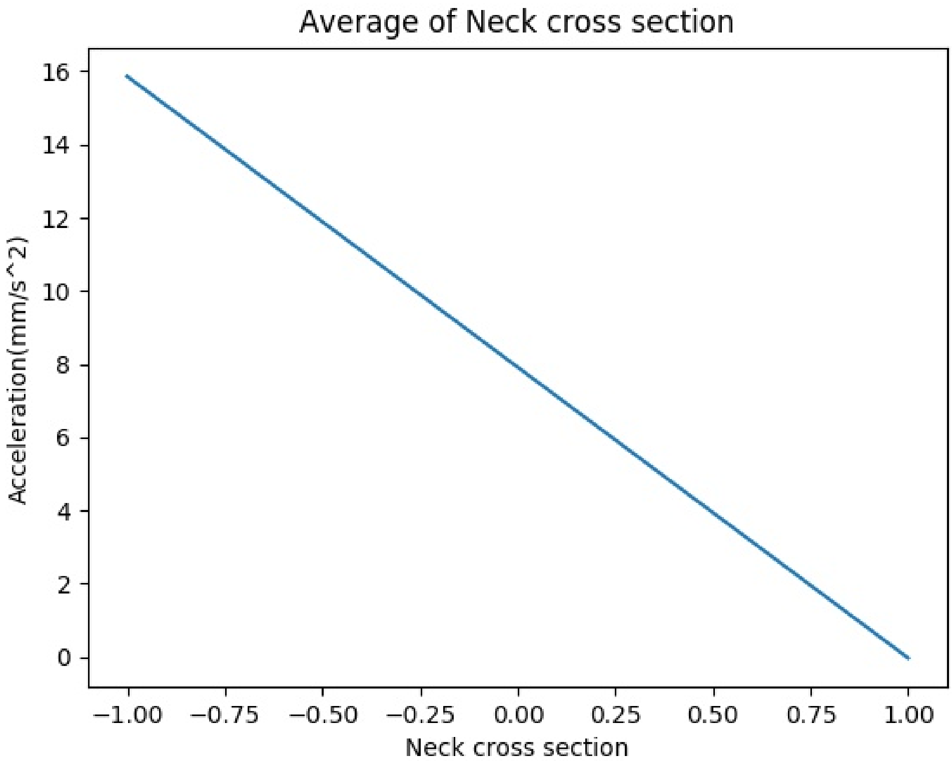


Figure 5.8. Average acceleration of Neck cross section.

Based on the test results shown in Figure 5.6, 5.7 and 5.8, we can see if we want to get maximum force, or to say, maximum acceleration, we should choose resonators with larger neck length, large volume, and smaller neck cross-section.

VI. Discussions

A. Experiment setup

We made several mistakes in the beginning of experiment setup.

We wrongly estimated the force can be produced by resonators.

It is actually very small. When other labs are doing this experiment, they usually use the best equipment to minimize the possible friction force as much as possible.

We predicted it to be rotating very fast at the very beginning, so our design focused on how to establish a stable experimental setup thus we used several bearings and heavy parts, which can make the experiment setup more stable, but also with much more friction force. (Figure 1)

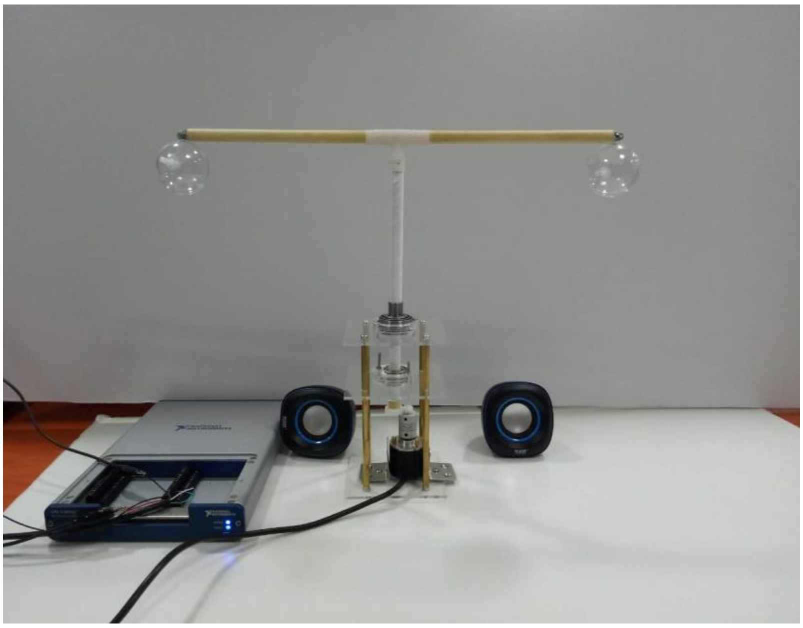


Figure 6.1 Initial experiment setup

We soon realized that this setup is too 'heavy' for our experiment. So we designed the final setup. Using every method we can think of to reduce the friction force.

Why first record one trial with sound and record another without sound?

This is because when we changed our experiment setup, we still find it hard to use the sound to drive the resonators rotating by themselves.

One solution under that condition is that we simply use louder sound source until it can activate the resonators.

But this will cause huge safety problems as well as disturbing other people in lab.

So we switched to another plan. We hope to analysis the difference between two trials, whose difference is made by the resonators.

By extracting data, we can find the phenomes made by resonators.

B. Uncertainty analysis

Uncertainty	Type
Uncertainty in electromagnet	Random
Uncertainty in encoder's low resolution	Random
Uncertainty in human operator	Random
Uncertainty in experiment setup (moment in x and y axis)	Random
Uncertainty in air turbulence	Random
Other uncertainty due to our ideal assumptions	Systematic

It is hard for us to calculate the above uncertainties, but we can do a rough approximation based on the data.

Acceleration made by friction is about 30mm/s^2, assume it has 10% turbulence, then compared to the results we obtained, we will have almost 100% uncertainty.

C. Why We don't use acceleration meters

Since it's not a good idea to get acceleration by differentiating position data, we can directly change to acceleration meters. The problem we encountered in the experiment is that the system is rotating; we cannot use a static acceleration meter connected to DAQ. Then we tried a Bluetooth module connected with an acceleration meter. This meter records acceleration with respect to gravity acceleration.

By this meter, we get several sets of data, take one of the data set as an example:

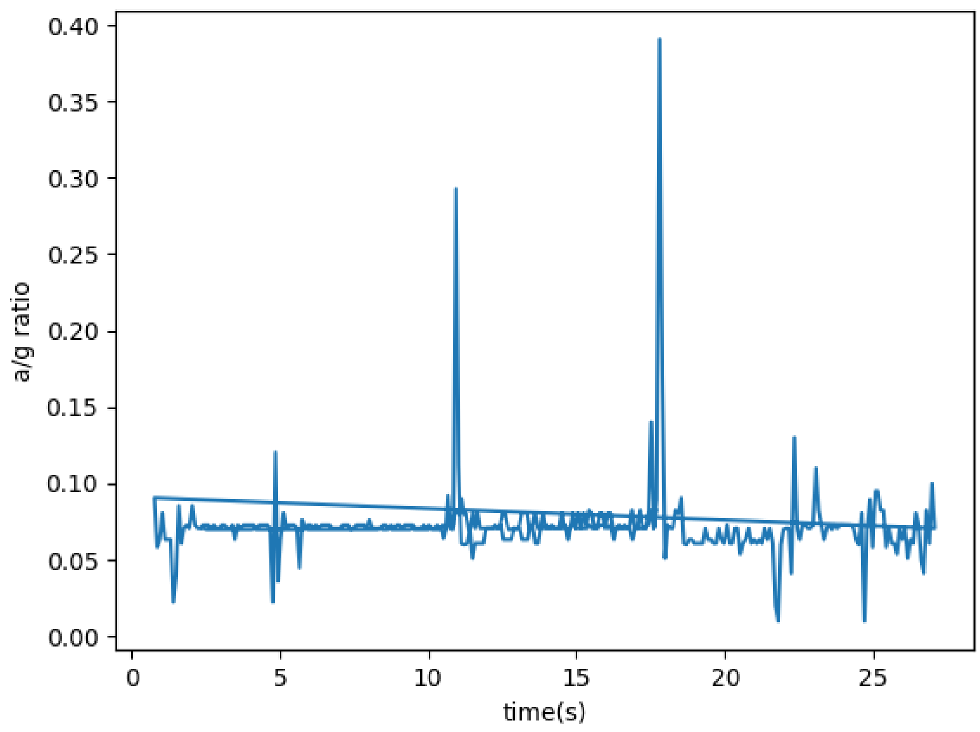


Figure 6.2 Acceleration data acquired by acceleration meter

There is again a lot of noise in the data, so we don’t get a better result compared to the encoder, so we stick to the encoder.

VII. Conclusion

Based on the test results, we can see if we want to get larger force, or to say, larger acceleration, we should choose resonators with larger neck length, larger volume, and smaller neck cross-section.

Meanwhile, although resonators can produce continuous force, it is too small and with large noise. The energy transfer efficiency is too low.

As a result, we should never consider transforming sound energy into kinetic energy unless better methods who can solve the above problems are available.

VIII. Gantt Chart

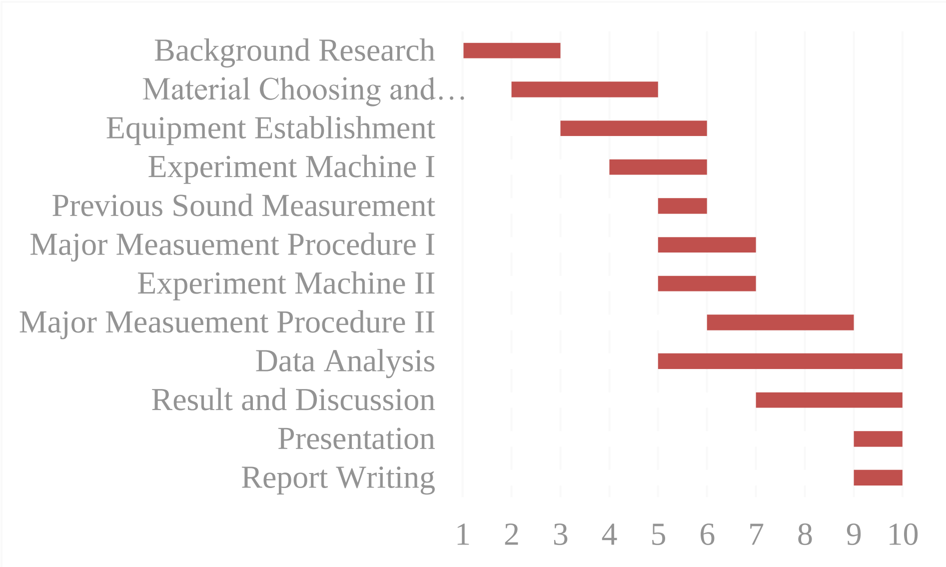


Figure 8.1 Gantt chart.

IX. References

[1]Vm495 Teaching Group," Lecture 2" *Vm495: Mechanical Engineering Laboratory II/ Summer 2017* [online material], Paper 16, [cited 10 August 2017]

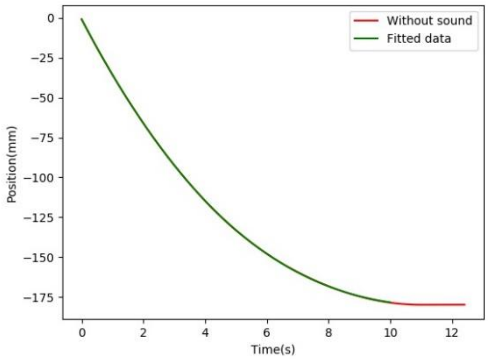
[2]A Selamet, I Lee, *Helmholtz resonator with extended neck*[Journal of the Acoustical Society of America]. Web, [cited 10 August 2017]

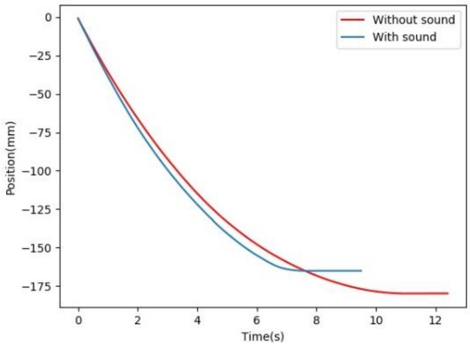
[3]OMRON, *E6B2-CWZ6C OMRON Rotary Encoder Specification*, 2012, [cited 10 August 2017].

X. Appendix

Raw data:

1st run:

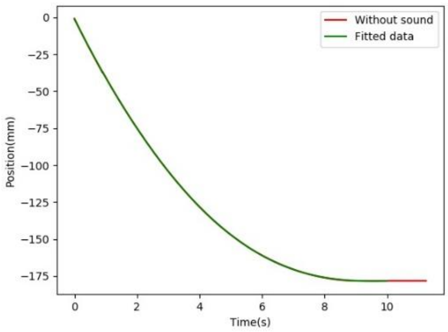


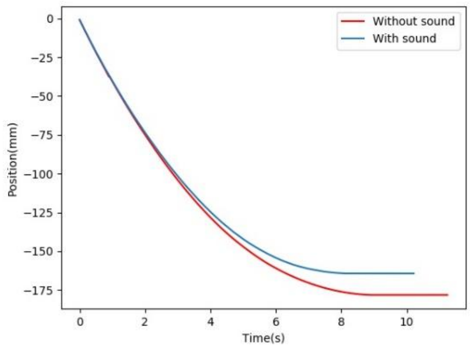


Raw data- Fitted data comparison

Time-position plot

2nd run:

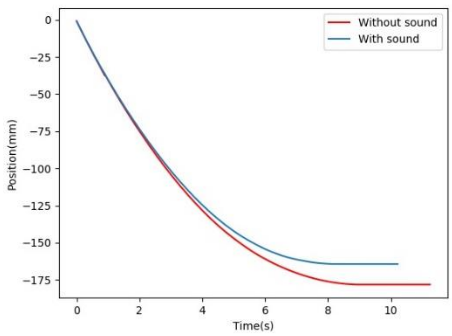


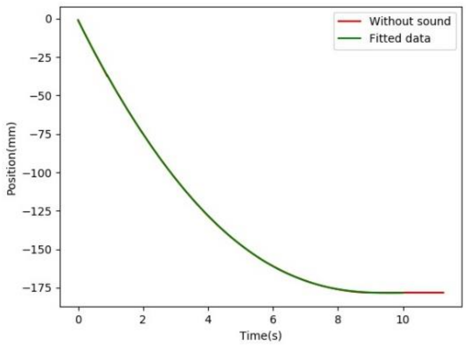


Raw data- Fitted data comparison

Time-position plot

4th run:





Raw data- Fitted data comparison

Time-position plot