THE CONSTRUCTION AND TESTING OF MULTIPLE SONOLUMINESCENCE VESSELS

by

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A THESIS

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Primary Thesis Advisor

Sonoluminescence is the emission of light from imploding bubbles in a liquid when excited by sound. It is thought that sonoluminescence is thermal and creates immense heat when the bubble collapses, which creates the light that is seen through experiments. This phenomenon has been well studied but there are unresolved theories on what is created when the bubble collapses. A question that warrants further investigation is about the vessels that help trap and produce sonoluminescence. The frequencies and resonances used to trap the bubble depend on the vessel or container being used. Containers vary in shape and size, but the most common vessels are spherical and cylindrical. This research project involves constructing several different vessels to test their different resonances and their effectiveness on trapping and producing sonoluminescence. Six total vessels were constructed for testing: two different sizes of spherical vessels, and 2 different radii of cylindrical vessels. There are multiple harmonics that can be found for a vessel were explored in this research project up to four harmonics for each vessel. With this in mind, the different resonant frequencies of the vessels were explored to see if there is a difference in suitability for sonoluminescence experiments between these vessels. This study intends to continue the development of sonoluminescence vessels and expand on sonoluminescence regarding the effectiveness of acoustic vessels.

Acknowledgements

I would like to take this time to thank Professor Bryan Boggs for acting as my primary thesis advisor, as well as providing support as I wrote my thesis. I am honored to have such an amazing professor guide me through the process of writing a thesis and my gratitude is immense. I would also like to thank my CHC representative Professor Corrinne Bayerl for providing feedback and support as I wrote my thesis. Finally, I would like to thank my parents for always being supportive of my studies and for always believing in my academic abilities, even if they didn't fully understand what I was doing.

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Introduction / Background Information:

Sonoluminescence is an interesting phenomenon because it starts with a fluid mechanic state described by hydrodynamic equations. An imposed sound wave can, in the presence of a bubble, focus its energy on the bubble, creating flashes of light as the bubble collapses. In other words, it is the process of converting sound into light. The bubbles concentrate the energy from the sound waves until they collapse, converting the sound into a flash of light. These focused energy flashes compared to the energy of a UV (ultraviolet) photon are 12 orders of magnitude higher, which is phenomenal (Brenner). Usually, the bubbles are so small and the sonoluminescence is so weak, that both make it hard for the human eye to see. This led to the discovery that the light appears as discrete flashes, which happen periodically within the sound field they are being produced in. In 1959, Erwin Meyer and Heinrich Kuttfruff wanted to find out in which phase of the sound wave the sonoluminescence occurred. They produced cavitation bubbles on an end face of a nickel rod and obtained a series of photos that showed the life cycle of the cavitation bubbles. “The photographs showed that the bubbles started to appear halfway through the sound period, grew to a maximum and collapsed rapidly. The sonoluminescent flash occurred at the end of the collapse.” (Young)

According to some researchers, the light from the collapsing bubbles can reach temperatures up to 12,000 Kelvin or around 21,000 degrees Fahrenheit. The mechanism that causes sonoluminescence is still unknown but there are some compelling theories. There are two different types of sonoluminescence: Single-bubble sonoluminescence (SBSL) and Multi-bubble sonoluminescence (MBSL). Before the 1990s, MBSL was the main method being used to explore sonoluminescence but wasn’t too reliable for exploring theories on bubble dynamics since they were based on SBSL. It wasn’t until the early 1990s that SBSL was achieved and it disproved a lot of theories but kept a few that fell into the categories of electrical or thermal reactions. It has been shown through experiment that the collapsing bubbles cause thermal emission. The processes that cause rapid thermal emission increases rapidly, which may be molecular, atomic recombination, and maybe even fusion. These fusion theories helped keep sonoluminescence relevant and popular for research, especially in the 1990s (Young). Since this research project focuses on the sonoluminescence vessels and not producing sonoluminescence, there is no need to study in depth these theories.

Bubbles are spontaneously created and are therefore hard to measure. To be able to study these collapsing bubbles, researchers figured out how to trap a single bubble in a standing wave antinode in a vessel that acts as an acoustic resonator. The standing wave allows for better measurements of this phenomenon allowing the bubble to expand and collapse over and over again in a periodic fashion.

Standing waves are waves that oscillate in time, but their peak amplitude does not move in space. These standing waves have what are called nodes and antinodes. Nodes are points on the standing wave that have strictly zero amplitude, while antinodes are points on the standing wave that may obtain maximum amplitude as seen in Figure 1. Some bubbles produced in the vessels are attracted to the antinodes of the standing waves. Acoustic radiation, or Bjerknes Forces, act on the bubbles pushing them towards or away from nodes/antinodes depending upon their size. If the correct vessel resonances (frequencies and amplitudes) are produced, then the amplitude of the standing wave will be large and stable enough to capture these bubbles. Once these bubbles are captured, the frequency can be tweaked just right where it doesn’t cause the bubble to escape its position, but instead collapse in on itself after expanding, producing sonoluminescence. This collapse can be reproduced indefinitely as the bubble reforms after it produces sonoluminescence.

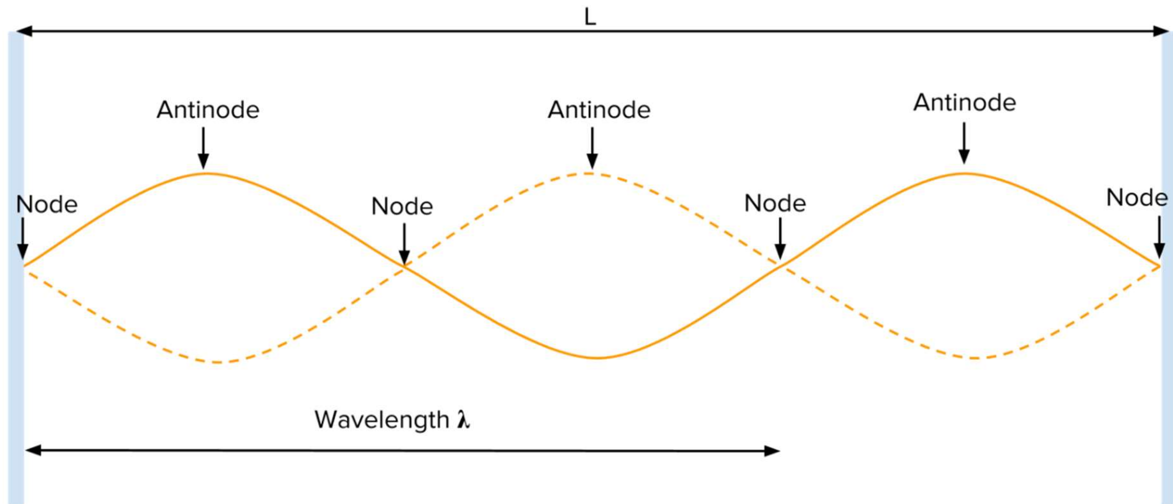

Fig. 1: Depiction of a standing wave showing nodes and antinodes

Resonators

According to photonics, the science of light and its use in technology, "A resonator is a device or system that exhibits resonance, which is a phenomenon that occurs when an external force or stimulus is applied at a specific frequency, causing the system to oscillate with increased amplitude" (*Resonator*). Acoustic resonators amplify or dampen specific frequencies of a standing wave. The waves bounce off the walls of the resonator, causing the waves to destructively interfere (cancel each other out) if they don't have the proper wavelength/frequency of the resonator, producing smaller amplitudes or zero amplitudes. Resonators can amplify specific sound waves of a system which matches its own natural frequencies, its resonance frequencies. If the wavelength matches the resonator, then the waves will constructively interfere (add to each other), producing larger amplitudes. When the resonators themselves vibrate at the same frequency as the driving waves, they will constructively interfere with each other. "In the case of standing waves, the relatively large amplitude standing waves are produced by the superposition of smaller amplitude component waves (resonator body)" (LibreTexts). This is similar to how some instruments produce specific notes when played. It is also similar to how blowing into a glass bottle produces different pitches depending on how much water is in the bottle.

To calculate the fundamental frequency of an acoustic resonator, one needs to know its geometry since this can affect where and how the standing waves reflect off its surface. One also needs to know the speed of sound in the medium one is using inside the acoustic resonator. This is because the speed of sound is different depending on what medium the wave is propagating through. For example, the speed of sound in air is approximately 340m/s while the speed of sound in water is approximately 1,500m/s. To be able to resonate, the vessel has to vibrate, like how on a guitar the strings get plucked and vibrate through the guitar body, which then resonates and produces a louder sound of the string plucked through the guitar body. To vibrate these vessels, piezoelectric transducers, or PZTs will be used.

For sonoluminescence, acoustic resonators are created using piezoelectric transducers (PZT) which are thin ceramic cylinders. These cylinders produce the external stimulus that causes the vessels to oscillate at specific frequencies. Each vessel has specific frequencies where it resonates most effectively. PZTs rely on the piezoelectric effect, which is defined as certain materials having the ability to generate an electric charge due to applied mechanical stress. "One of the unique characteristics of the piezoelectric effect is that it is reversible, meaning that materials exhibiting the direct piezoelectric effect (the generation of electricity when stress is applied) also exhibit the converse piezoelectric effect (the generation of stress when an electric field is applied)" (*The piezoelectric effect*). This oscillating voltage causes the PZT to expand and contract, creating sound wave frequencies through vibrations. These PZTs are attached to vessels filled with deionized water where resonant frequencies are produced to trap forming bubbles. Since the piezoelectric effect is reversible, it allows for another PZT to record the induced frequencies being produced by the vessels. In our case, deionized water is used to reduce unwanted complications when recording data because water can contain other particles that may interfere with the sound waves being produced.

Materials and Methods:

Construction of Vessels

With the background on sonoluminescence and acoustic vessels covered, one may now discuss how to construct and test these sonoluminescence vessels. Each vessel has specific resonance frequencies that depend on the shape, size, and material being used. To test these properties, six different vessels were constructed for this project. Here is a list of the materials used to construct these vessels below:

- One large 500 ml glass spherical flask, 12 cm diameter
- Three small 100 ml glass spherical flasks: one clear neck flask, two opaque neck flasks, all with the same diameter of 5.5 cm
- One large custom 1000 ml plastic/acrylic cylindrical flask (diameter = 12 cm, height = 12 cm, wall thickness = 3 mm)
- One small custom 250 ml plastic/acrylic cylindrical flask (diameter = 5.5 cm, height = 12 cm, wall thickness = 3 mm)
- 12 medium-sized PZTs, inner diameter: 1 cm, outer diameter: 3 cm, thickness: 5 mm
- 6 small (button) PZTs, diameter: 2mm, thickness: 1 cm
- Wire
- Solder
- Deionized water
- High Voltage Amplifier System
    - Function Generator
    - High Voltage Amplifier

- Oscilloscope
- Temperature Controller

- Gorilla Glue Epoxy
- Custom clamps/stand for vessels

PZTs:

The PZTs are ceramic, cylindrical washers/disks that when induced with a voltage expand and contract. To do this, black and red wires were soldered to each disc. The black wires are ground and the red are positive. Each PZT gets three red and three black wires for wiring redundancy. Positive side is indicated by a dot on one side of the PZT. Red wires go on the dot side while the black wires go on the other side. PZTs are sensitive to heat or thermal shock, so extra precaution is taken when soldering the wires onto the surface of the PZT. A benefit to the piezoelectric effect, mentioned in the introduction, is its reversibility. This means that the PZTs can be used to produce the resonant frequencies and record the induced response. Consequently, another disk-shaped PZT will be used to record the induced response. This single PZT is smaller than the other PZTs and will be referred to as the button PZT. The button is put on the bottom of the spherical vessels and on the side of the cylindrical vessels. As evident in figure 2, the compressing and expanding of the PZT produces voltage, forming a circuit that flows from positive to negative. The PZT acts similar to a battery, having a positive and negative side. If one puts in a battery the wrong way into a remote it will not function properly. Just like a battery, if it is not wired properly or plugged into the voltage amplifier correctly, it will not function properly.

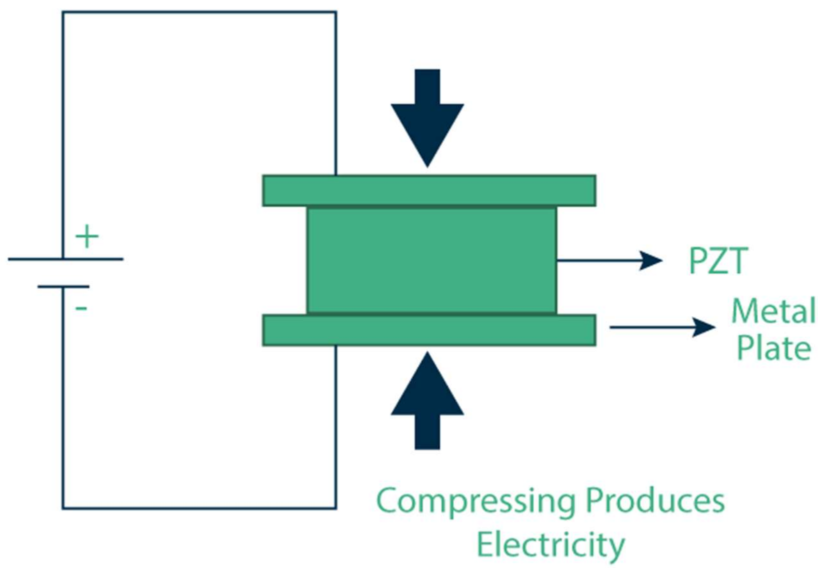

Fig. 2: A diagram of a piezoelectric transducer (PZT)

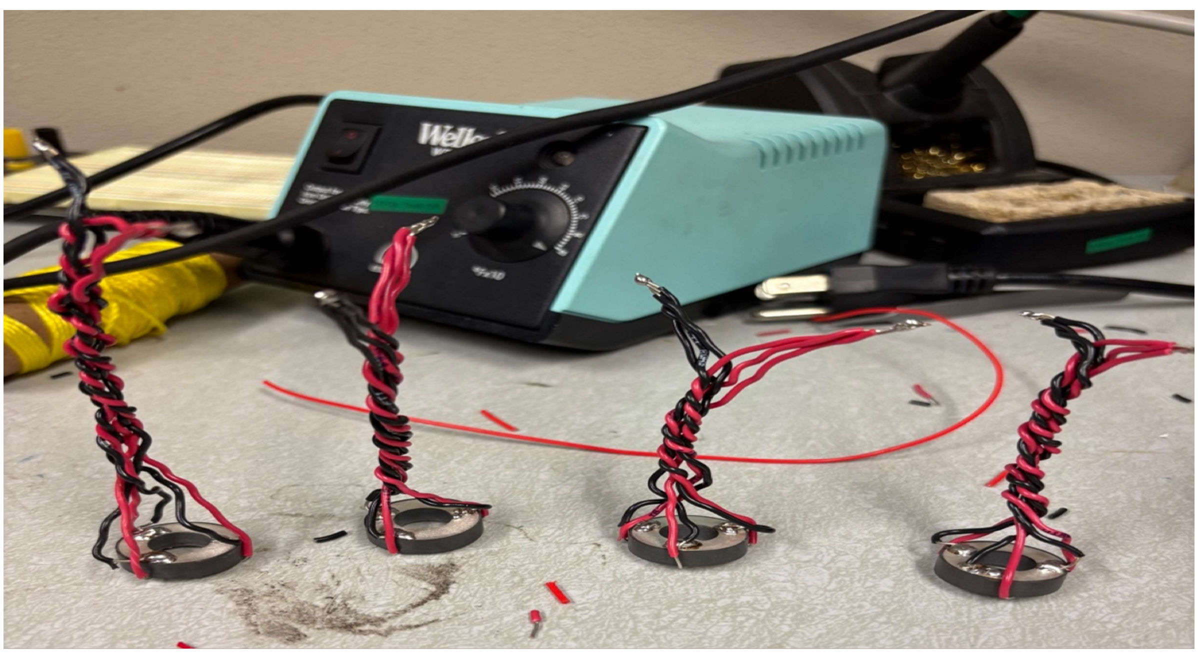

Fig. 3: Picture of correctly soldered PZTs ready for testing

Each PZT has three black and three red wires where red is positive and black is ground.

To test that the PZTs are functioning, each disc is hooked up to the High Voltage Amplifier and function generator separately for individual testing, which is called the “Hum” method. It is called this since once the amplifier is turned on, the PZT will make a humming sound if it is constructed properly. This hum will increase or decrease in pitch depending on how high or low the frequency is. The testing frequency will range from 7kHz-16kHz which is in the range of human hearing and gives a good range for the PZTs to hum. A drawback to this testing method is the fact that it is limited to the human range of hearing, so one is not observing the higher and lower frequencies that the PZT should be producing. This test is sufficient enough even with this drawback as it is primarily used to make sure the soldering process, the wires, and the PZT itself, are functioning properly before the PZTs are attached to the flasks. The epoxy is a very strong adhesive. Once it is set it can be very difficult to take off if the PZT is not functioning, even damaging the vessel or PZT.

High Voltage Amplifier

Before going any further, one must know what is being used to activate the PZTs and produce resonance frequencies in the vessels, which is the high voltage amplifier system. The amplifier system consists of a power supply ($22V$) which feeds into the DC/DC converter to set two voltage 'rails' at $\pm 400V$, each rail is connected to a 2.5 MHz low pass filter and into a separate RC low pass filter. The rails connect to the amplifier and the amplifier is set to a gain of 73. The RC low pass filter removes much of the transmission noise at $160Hz$ and up while the inline filters filter out the high MHz bands thus isolating the amplifier from many of the unwanted noise sources. A schematic is shown in figure 4. All the filters make it so there is minimal noise when recording data using an oscilloscope. Even with all the filters there will still be noise as it is not a perfect system. This system will be accurate enough to obtain the data needed from the acoustic vessels. The amplifier can heat up very quickly where the max operating temperature it can reach is 85°C, so it needs proper ventilation and cooling. To do this, a medium sized fan is attached to the amplifier box. A thermal-electric-cooler (TEC) is also directly attached to the amplifier that monitors and controls the internal temperature and tries to keep it at around 20°C. To produce sonoluminescence, this devise must produce high voltages and high currents which can be lethal. Proper safety must be practiced when using this device.

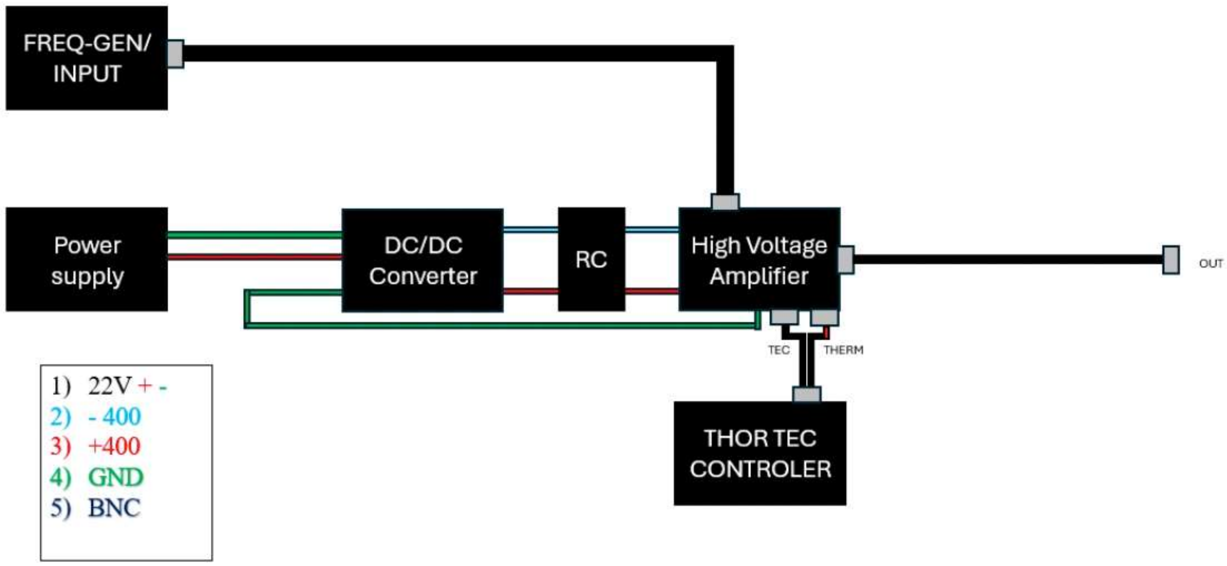

Fig. 4: Schematics of the High Voltage Amplifier System with filters and cooling system

Combining Flasks and PZTs

Once all the PZTs are tested and function properly, they will be attached using Gorilla Glue Epoxy to the spherical and cylindrical flasks. Epoxy is used since it is a strong binding material and is very stiff, which allows the PZTs to vibrate through it to the flasks. Using rubbery or soft binding material may absorb some of the vibrations of the PZTs, skewing the data. The recording PZTs, or the button mic, will be attached similarly as well. The epoxy can take up to a day to fully settle and adhere, so one vessel was fully constructed and tested before constructing the rest of the vessels. This process of testing the PZTs then attaching them to the vessels is repeated for each vessel. Vessels were constructed and tested one at a time. Once the

PZTs are attached, the vessels will be ready for testing. The spherical flasks will be tested by clamping them to a custom rig that suspends the vessel above the table shown in figure 5. This allows the PZTs to vibrate the flask with minimal energy loss to the table. Since the cylinders diameter is too large to be clamped into the custom rig, they will be slightly elevated above the table so that the PZT on the bottom of the cylinder does not touch the table itself shown in figure 5.

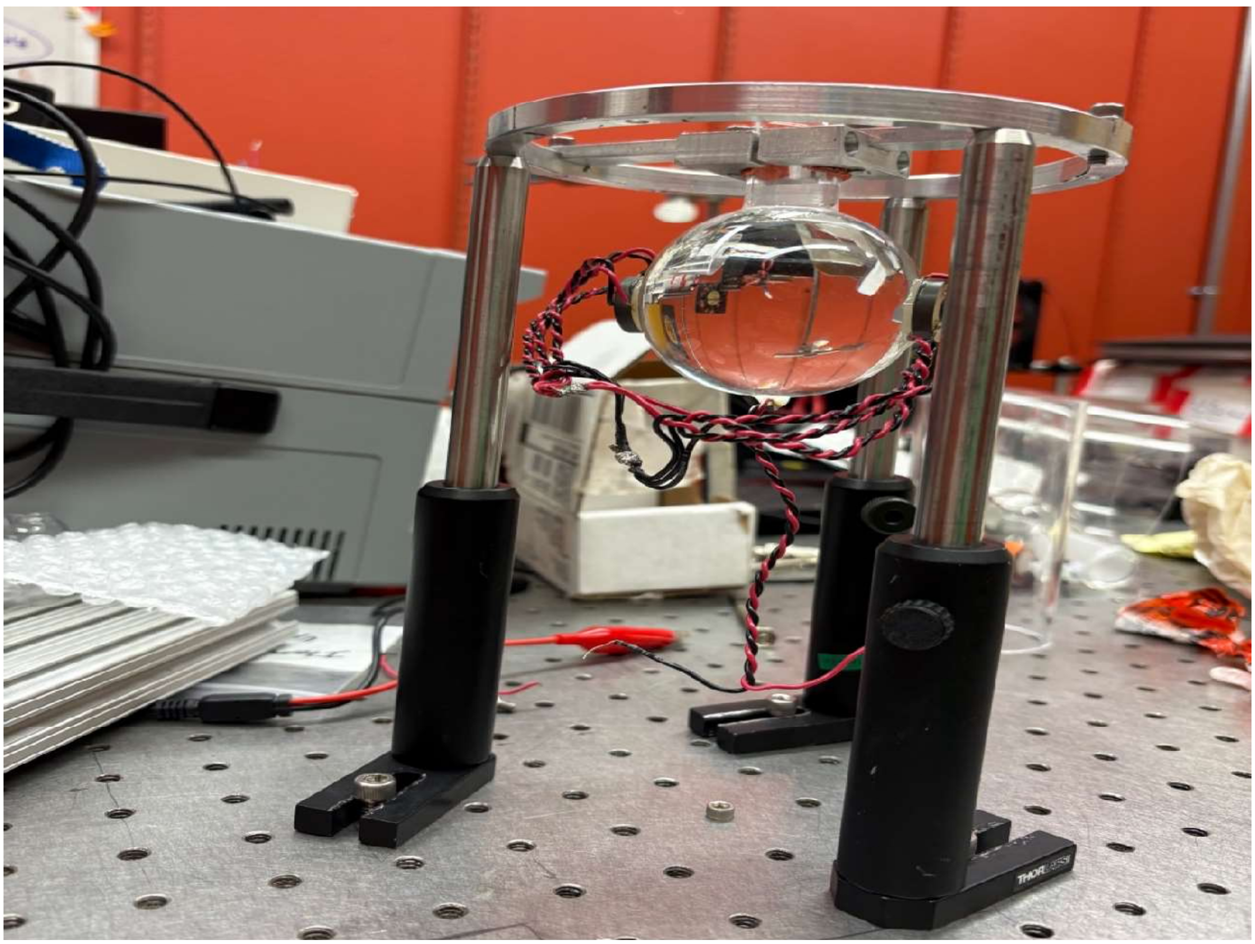

Fig. 5: Fully Constructed vessel fitted into clamps ready for testing.

Completed Vessels

With the completion of attaching PZTs to the flasks, the vessels are ready for testing. Below are pictures of each vessel fully constructed. As shown in figure 6-11, each spherical vessel has two or four PZTs on the circumference of the flasks and has one small (microphone) PZT on the bottom of the flask. Each cylindrical flask has one PZT on the bottom of the flask and one small (microphone) PZT on the side of the flask. All the spheres are made of glass while the cylinders are made of clear plastic/acrylic. Since there are three spherical flasks that are the same size, they will be differentiated by their necks. The small spherical flask for group one will be described with a clear neck as shown in figure seven. The small spherical flasks for group two will be described with an opaque neck as you cannot see through these necks of the flasks as seen in figure 8 and 9. To further differentiate the opaque neck, small spherical flasks, they will be described by how many PZTs they have. For example, the flask in figure nine would be described as an opaque neck, small spherical flask with four PZTs.

Group 1:

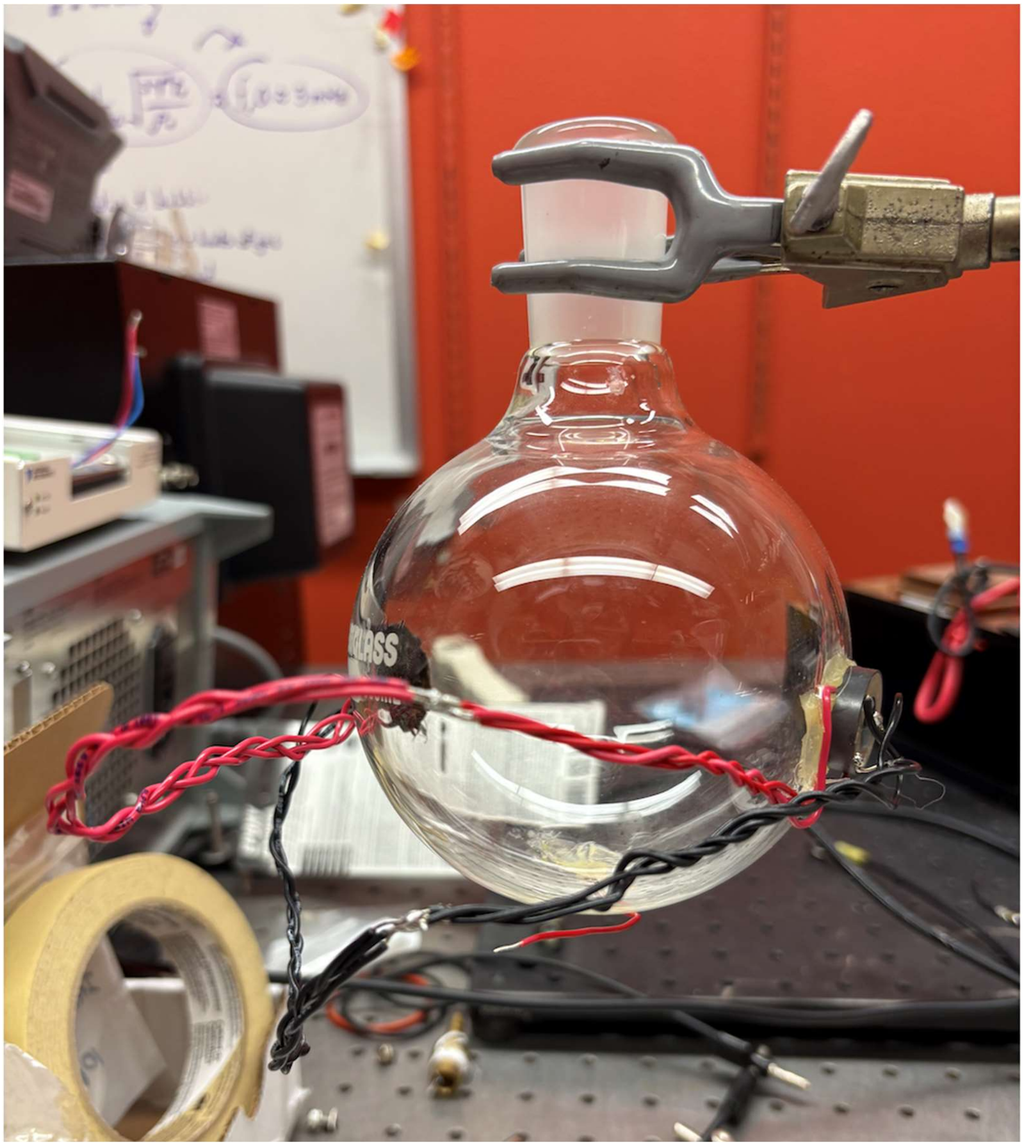

Fig. 6: Large 500 ml spherical flask, two PZTs

Fig. 7: Clear neck, 100 ml small spherical flask, two PZTs

Group 2:

Fig. 8: Opaque neck, small 100 ml spherical flask, two PZTs

This spherical flask has a neck that connects to "shoulders" of the sphere as compared to the clear neck sphere in figure 7 that has no "shoulders".

Fig. 9: Opaque neck, small 100 ml spherical flask, four PZTs

This spherical flask has “shoulders” that connect the neck to the body of the sphere the same as the sphere in figure 8.

Group 3:

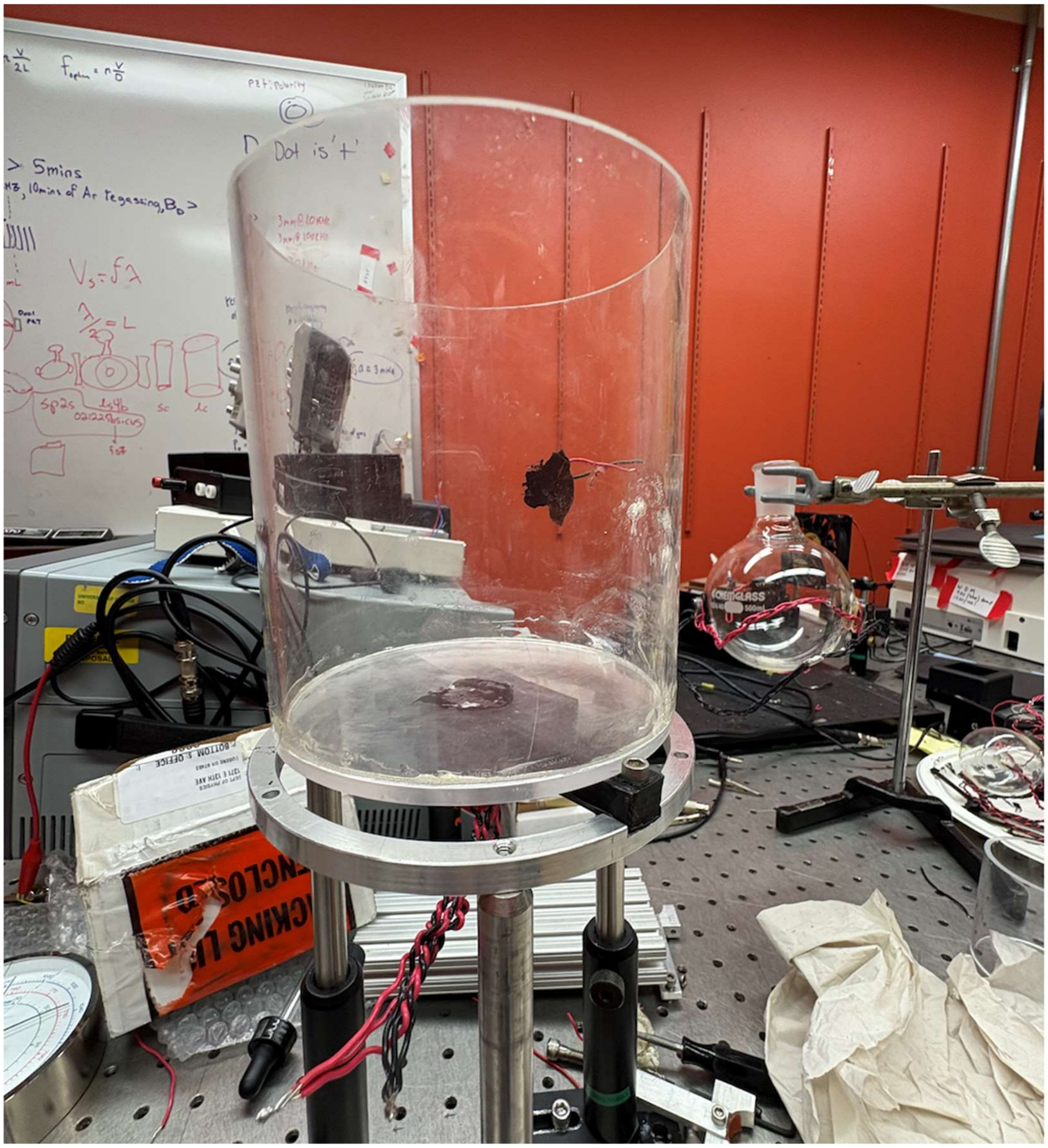

Fig. 10: Large cylindrical flask

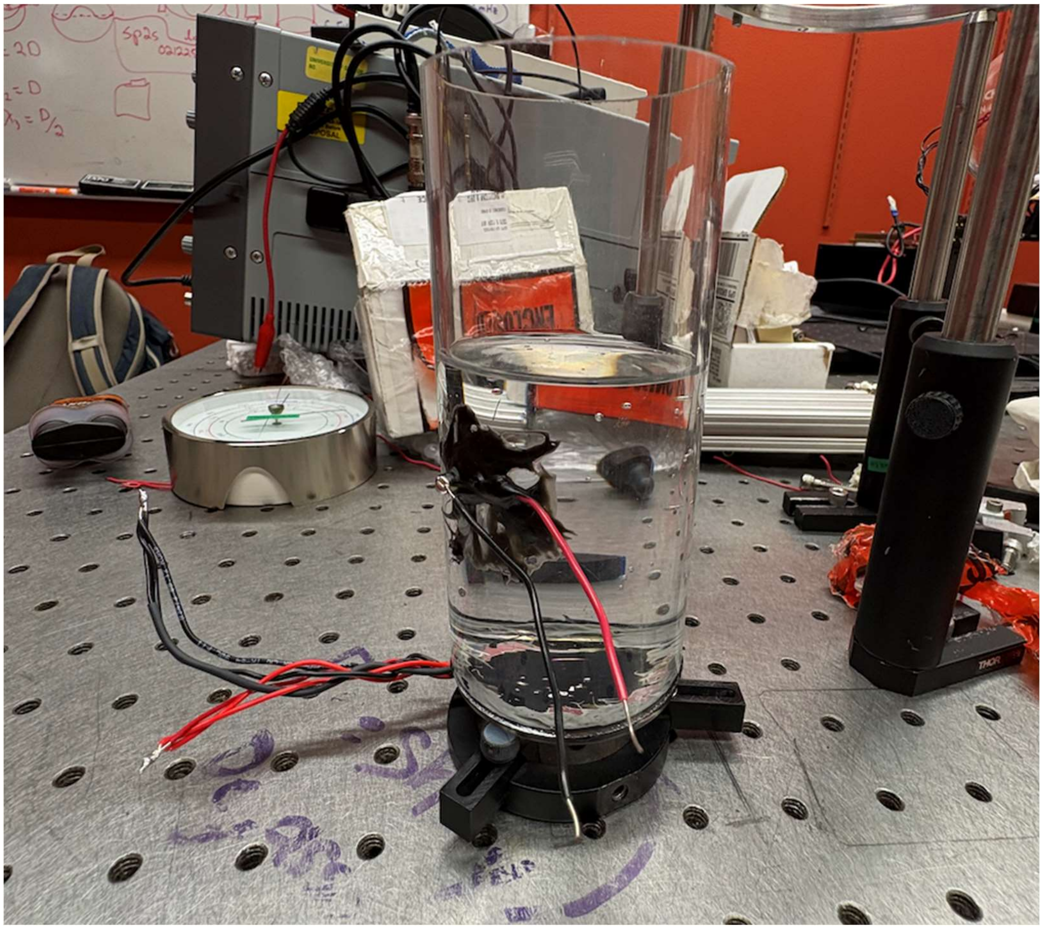

Fig. 11: Small cylindrical flask

Calculating Resonances

Before taking data on the resonance frequencies, the expected resonances of each vessel will be calculated. To calculate frequencies, $f = n(v/D)$ will be used to calculate resonance frequency for the spheres and $f = n(v/2D)$ for the cylinders. The resonance frequency equations were derived from equations in the paper “On the Theory and Design of Acoustic Resonators” by Uno Ingard. “D” is the diameter of the sphere and the diameter of the cylinder, “v” is the speed of sound in water, which is approximately 1,500 meters/second. “n” is the number of antinodes in a standing wave, or the number of harmonics. “f’’ is the calculated resonance frequency in Hertz. Up to seven harmonics will be recorded in the broad-spectrum tests, so n = 1,2,3,4, etc. There is more focus on the odd harmonics since they produce standing waves with antinodes, or peak amplitudes, in the center of the vessel, which is ideal for capturing and analyzing SBSL. Calculating these resonance frequencies gives a basis for the spectrum of frequencies that will be explored when taking data. The large sphere has a diameter is 9.7 cm and the diameter of the three small spheres is 5.5 cm. The large cylinder has a diameter of 12 cm and the small cylinder has a diameter of 5.5 cm. The height of the cylinders is the same at 12 cm. These differences in size can be seen in the figures 6-11 in the previous section above. This project analyzed how changing the diameter affects produced resonance frequencies, i.e. the radial resonance frequencies. The goal of this study was to find out whether changing the height, or length of the cylinders would affect the axial resonance frequencies of the cylinders.

Resonance Number	1	2	3	4	5	6	7
Vessel	**Resonances (kHz)**						
Large Sphere	12.5	25.0	37.5	50.0	62.5	75.0	87.5
Small Sphere	26.5	53.1	79.6	106.2	132.7	159.2	185.8
Large Cylinder	6.3	12.5	18.8	25.0	31.25	37.5	43.75
Small Cylinder	13.6	27.3	40.9	54.6	68.2	81.8	95.5

Table 1: Table of calculated resonance frequencies of each vessel shape/size

Although there are three separate small spheres being tested, this calculation of the resonance frequencies of the small sphere pertains to all the small spheres.

Data Collection/Analysis:

To complete the resonance tests, the high voltage amplifier system will be used that was used to test the PZTs. The amplifier is connected to a function generator, which will input a set of fixed amplitude sine waves with frequencies that can be manually increased or decreased. The PZTs are connected to the amplifier and the button mic output is put into the oscilloscope. The amplifier and function generator are also connected to the oscilloscope to make sure the driving voltage stays positive because producing negative functions could damage the PZTs. The function generator will be preset to 20kHz sine wave, 1.0 Vpp, and an offset around negative 800mV. The offset is what keeps the PZT driving voltage positive. Once everything is plugged in properly and the function generator presets are put in, the amplifier can be turned on for data collection. The first data collection will be a broad spectrum of each flask. This will range from half the first calculated resonance frequency to four times the calculated resonance frequency. This spectrum will be recorded in increments of 100Hz. To find the resonance peaks, the oscilloscope will measure Vpp from the button PZT. Vpp measures the voltage of the frequency being produced from crest to trough of the standing wave, which is measured in milli-volts (or mV). This can visually be seen on the oscilloscope as the wave will become “taller” or larger on the screen as shown in figure 12.

The six flasks will be put into three separate groups for testing. The first group will be testing the effects of resonances due to size. This group will compare the large 500 ml sphere and the clear neck 100 ml sphere. Both spheres will only have two PZTs since it is the size difference that is being tested, not the amount of PZTs. The amount of PZTs will be tested in the second group with two opaque neck 100 ml spheres where one sphere will have two PZTs while the other will have four PZTs. The last group will be testing two things: if the size affects resonance, and if a different shape is beneficial for resonance and producing sonoluminescence. This group will be comprised of the small 250 ml cylinder and the large 1000 ml cylinder.

Once the broad spectrum is completed, calculated resonances will be compared to the peaks from the broad-spectrum data. The closest peak to each of the four calculated resonances will be used for closer analysis of each peak. This will be a focused spectrum of the peaks to get a more accurate reading of where each peak is. The best peaks for SBSL are the ones that will produce a resonance frequency with antinodes in the center of the vessel. These will be the odd harmonics. The increments of increase in frequency for data collection for the focused spectrums will be around 10Hz. The data for each of the two vessels of the three groups will be compared to each other to see if there are any similarities or differences. Peaks that look out of place, or “anomalies”, will be analyzed further by retaking measurements to see if it is worth looking into or if it is from excess noise, which then it would not be worth analyzing further. These “anomalies” are interesting as this is potentially where new science is.

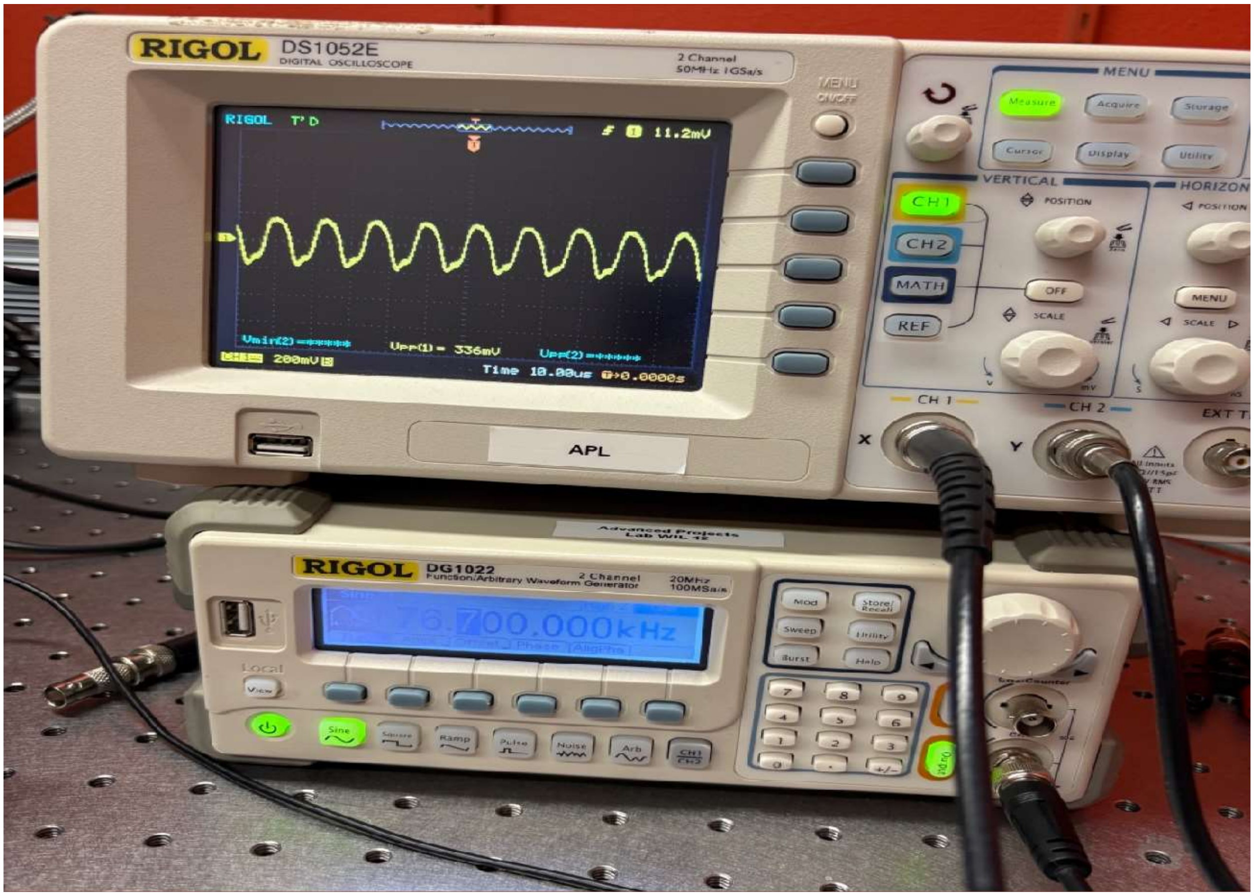

Fig. 12: Image showing the function generator (bottom box) and oscilloscope (top box) being used with the high voltage amplifier

Broad Spectra:

The first data taken were the broad spectra of each flask. As mentioned before, the six vessels were put into three different test groups that isolated different aspects of an acoustic vessel to test. The first group is the size difference, the second group is the different number of PZTs, and the last group is shape difference. Below will be all the broad-spectrum data from each vessel group.

Group 1:

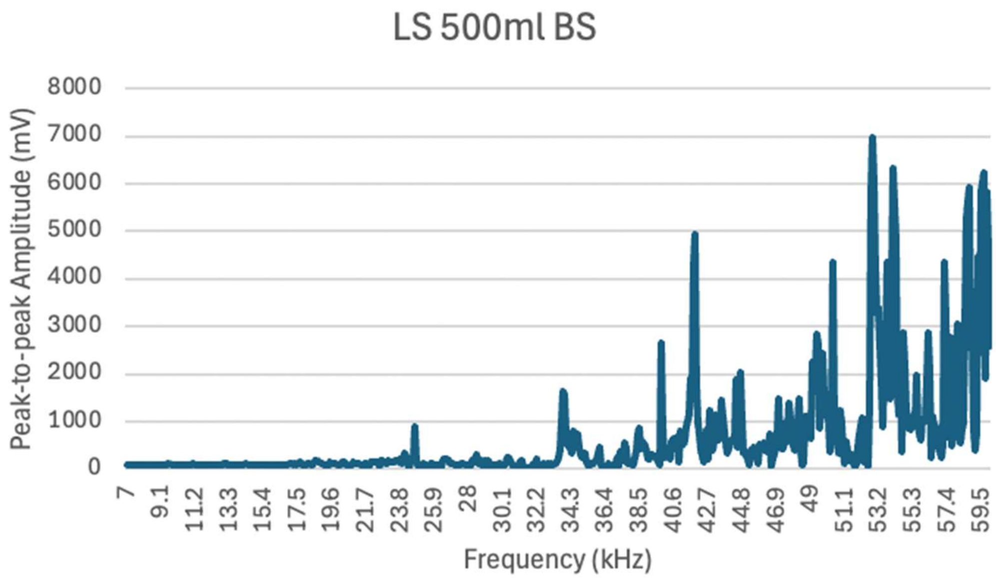

Fig. 13: Broad Spectrum of large 500 ml spherical flask with 2 PZTs

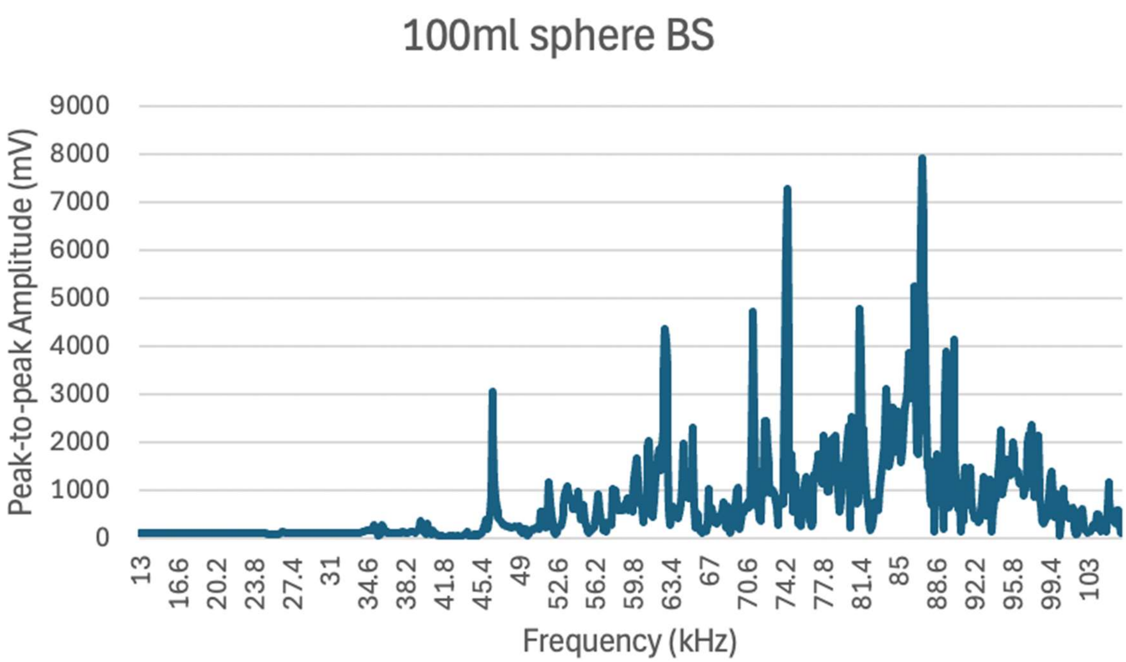

Fig. 14: Broad Spectrum of clear neck 100 ml small spherical flask with 2 PZTs

Group 2:

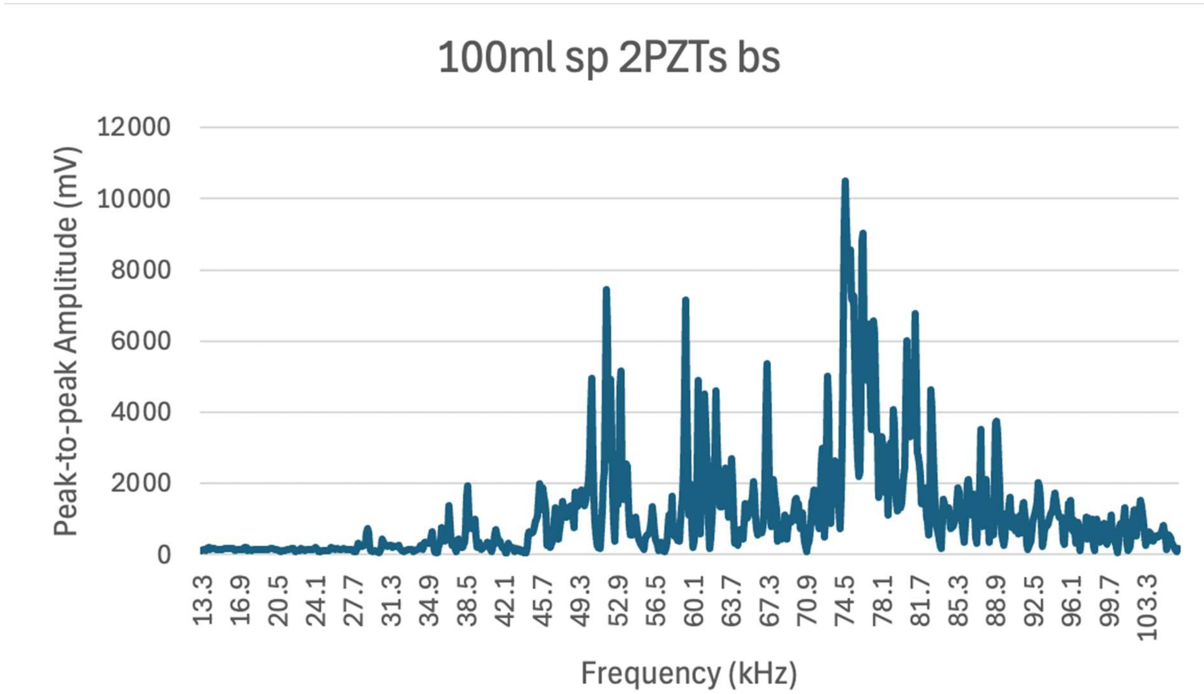

Fig. 15: Broad spectrum of opaque neck 100 ml small spherical flask with 2 PZTs

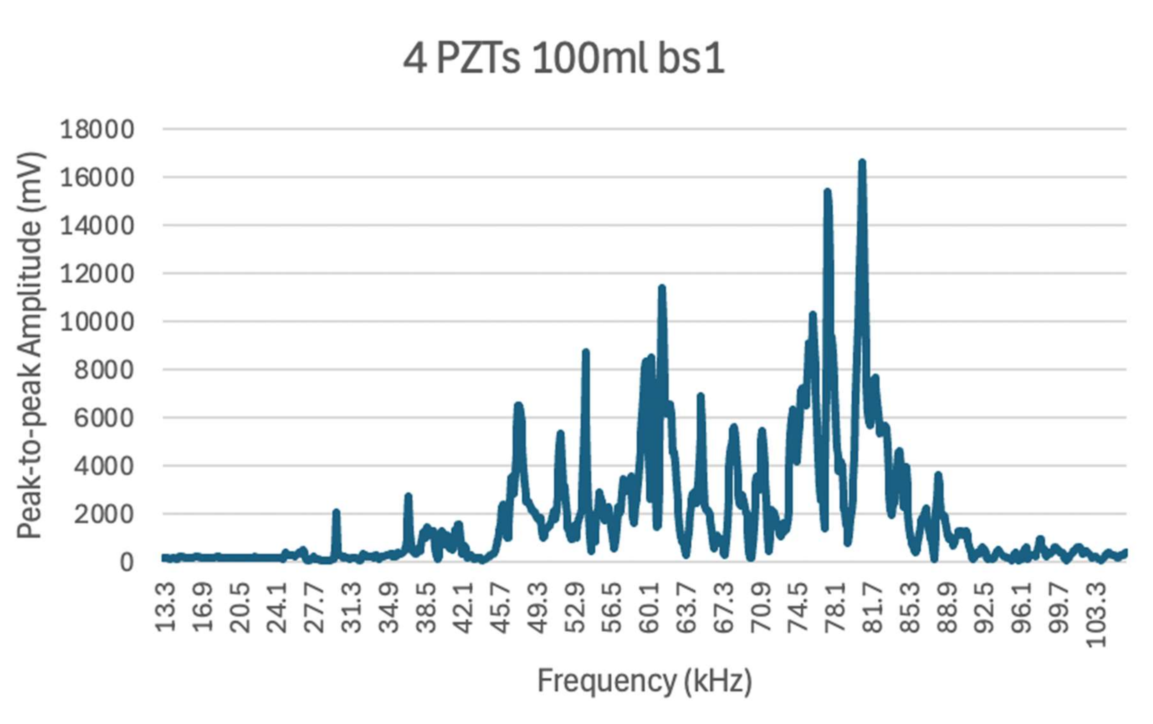

Fig. 16: Broad spectrum of opaque neck 100 ml small spherical flask with 4 PZTs

It was the first time we observed resonance data for the broad spectrum of a four PZT flask. The extra two PZTs altered the spectra as compared to the 2-PZT flask, so it was hard to tell from one data collection if the peaks were actually resonance peaks or not. To make sure the broad spectrum was repeatable, another set of data was taken of the broad spectrum: One set taken from 13.3 kHz to 35 kHz, shown in figure 17 and18, the other set taken from 65 kHz to 106 kHz, shown in figure 19 and 20. These two data sets were then compared to the first broad spectrum data set as seen below:

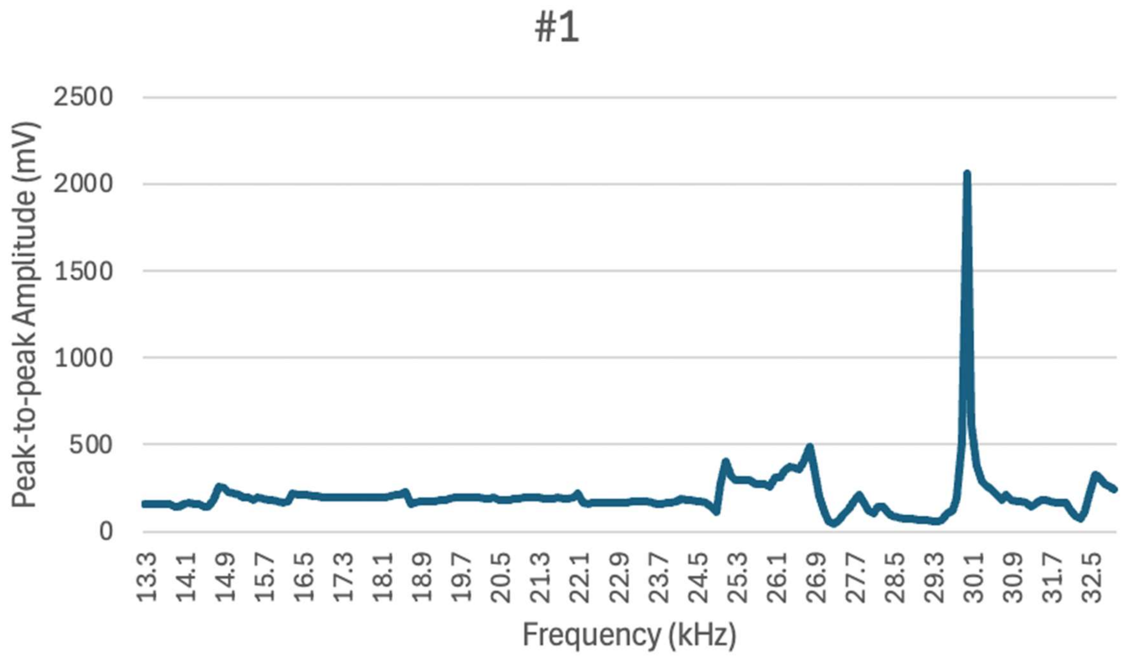

Fig. 17: Part of broad spectrum of opaque neck 100 ml, four PZT small spherical flask, data set 1 from 13.3-33 kHz

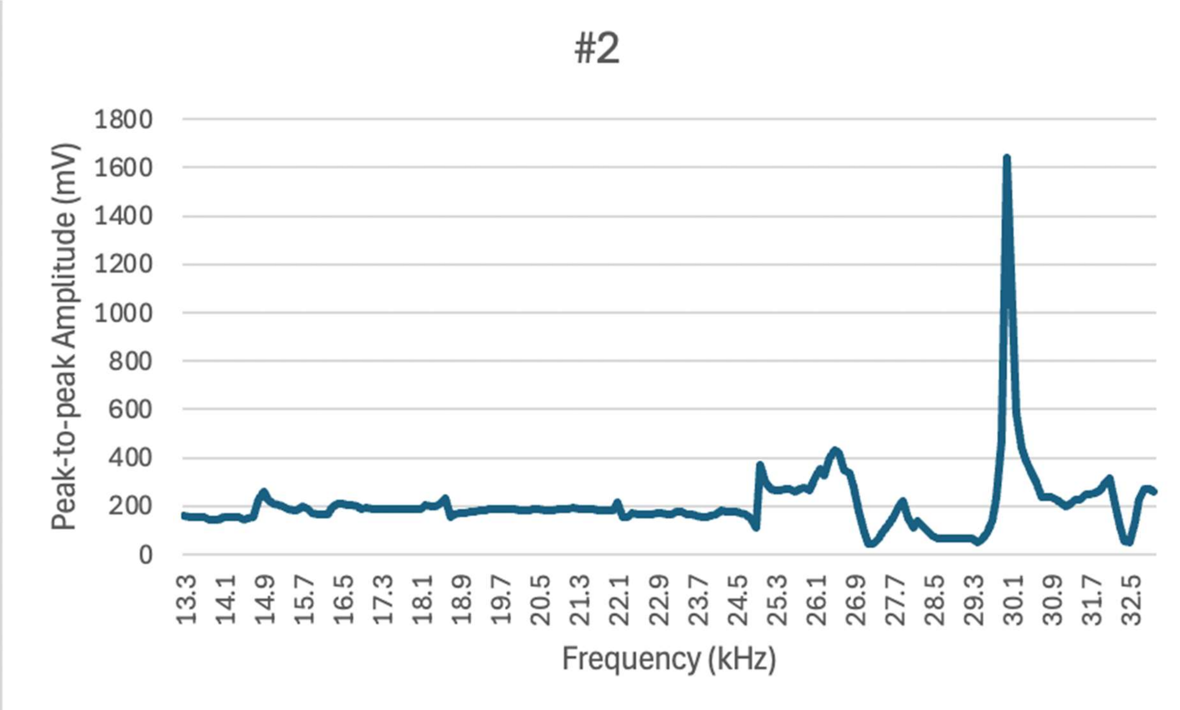

Fig. 18: Part of broad spectrum of opaque neck 100 ml, four PZT, small spherical flask, data set 2 from 13.3-33 kHz

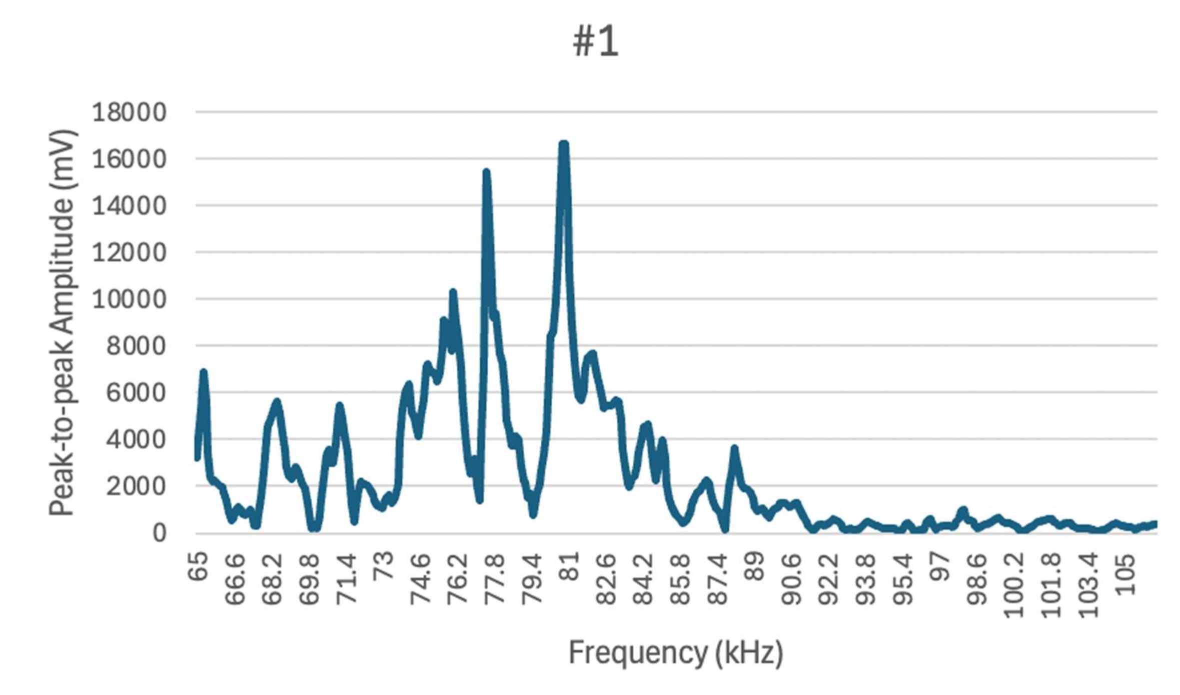

Fig 19: Part of broad spectrum of opaque neck 100 ml, four PZT, small spherical flask, data set 1 from 65-106 kHz

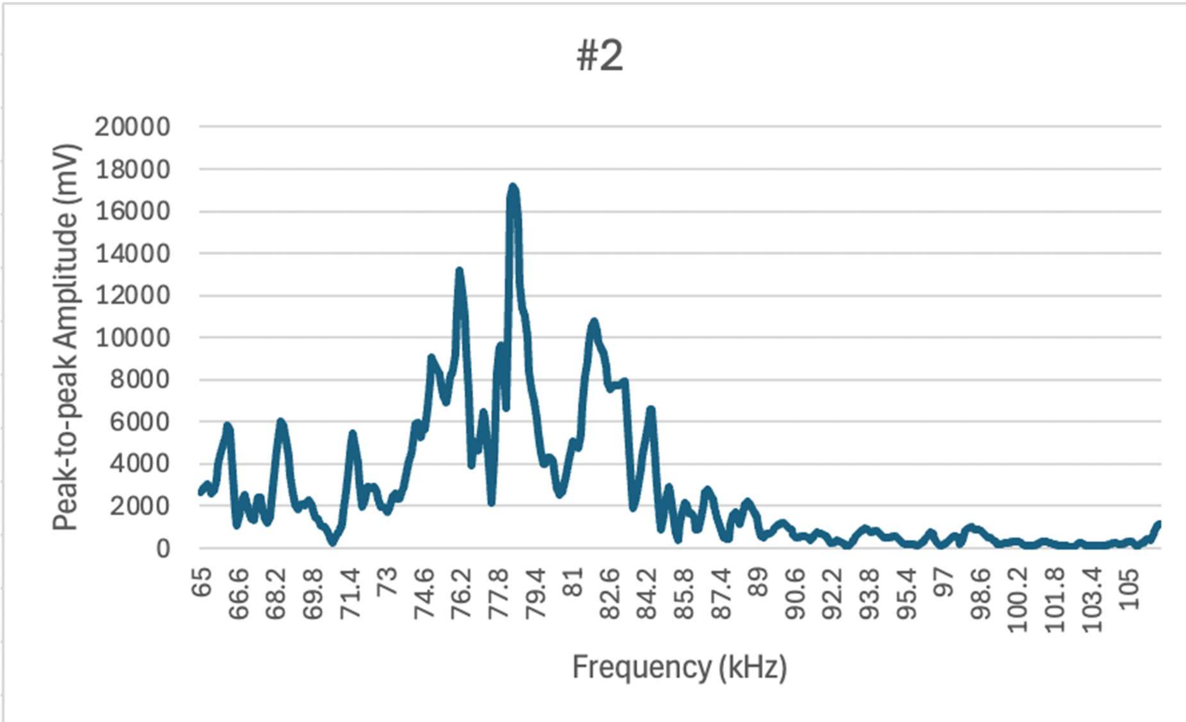

Fig. 20: Part of broad spectrum of opaque neck 100ml, four PZT, small spherical flask, data set 2 from 65-106 kHz

A comparison of data sets 1 and 2 for the 4-PZT flask show the spectrum is repeatable.

Group 3:

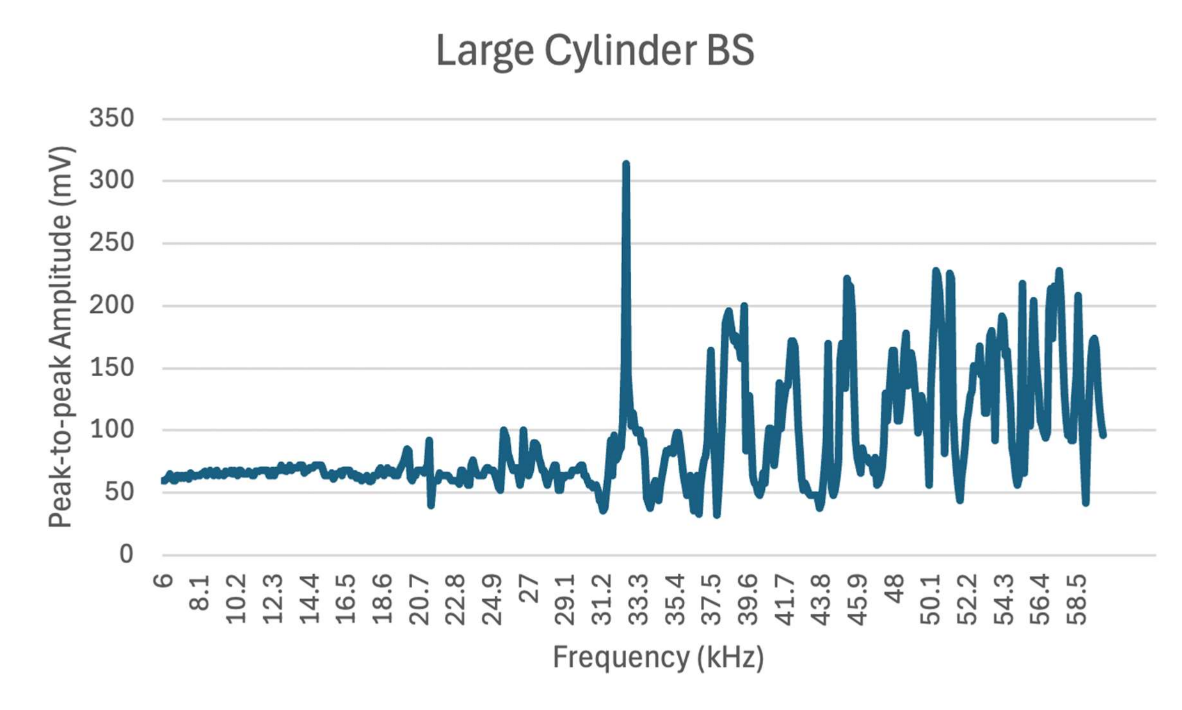

Fig. 21: Broad Spectrum of large cylinder one PZT

This broad spectrum likely includes radial resonances as well as axial resonances.

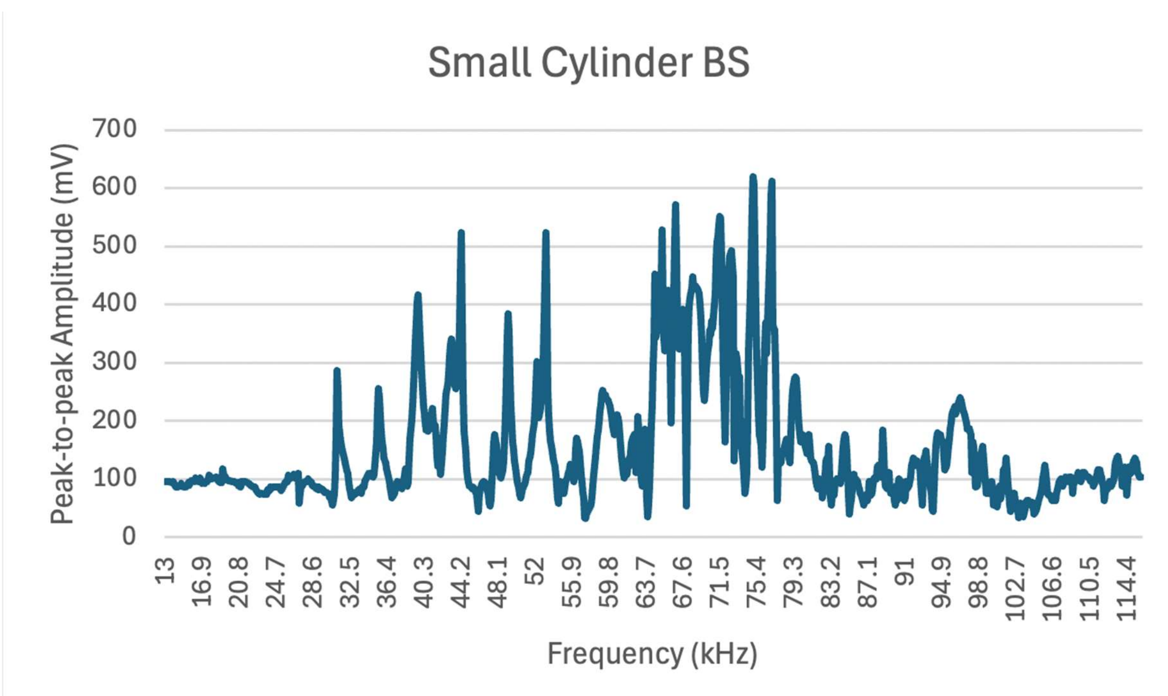

Fig. 22: Broad Spectrum of small cylinder one PZT

This broad spectrum likely includes radial resonances as well as axial resonances.

Focused Spectra:

Now that the broad spectra have been established, we can look at the four chosen resonance peaks that were closest to the calculated resonances. Each vessel had data taken for four peaks that were the closest to the calculated resonances. To get a sharper and closer look at these resonance peaks, the frequency was increased in increments of 10 Hz, instead of 100 Hz for the broad spectrum.

Group 1:

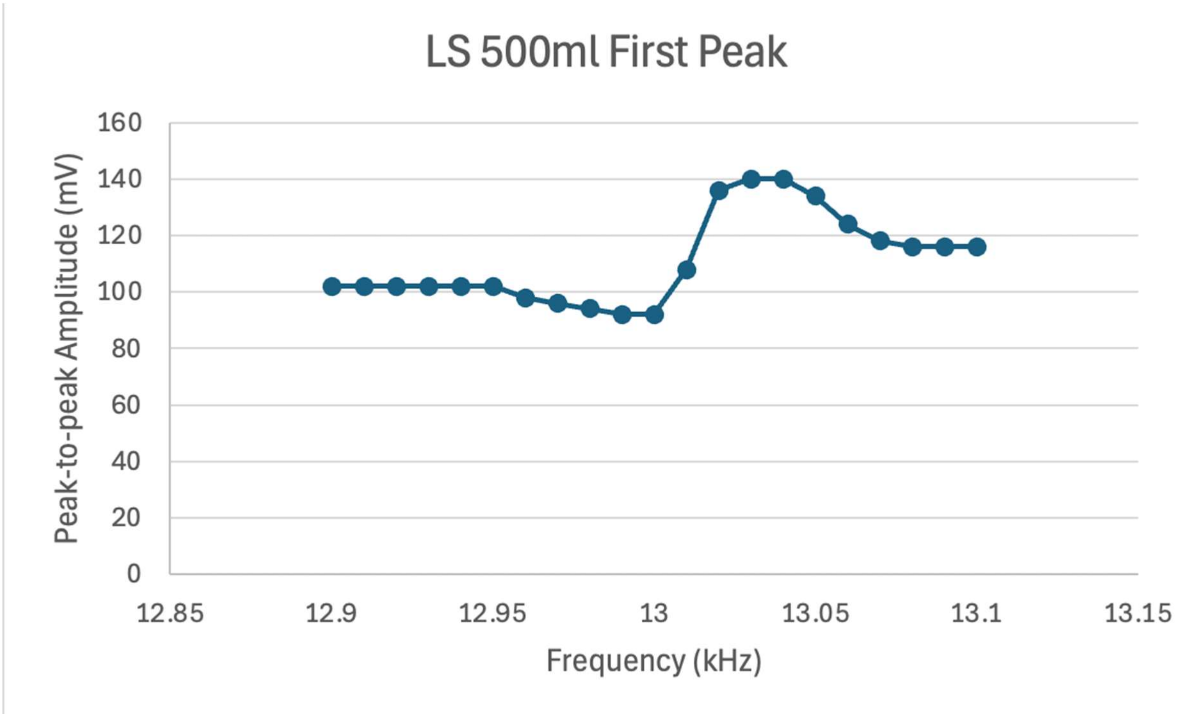

Fig. 23: First resonance peak from 500 ml large sphere, two PZTs

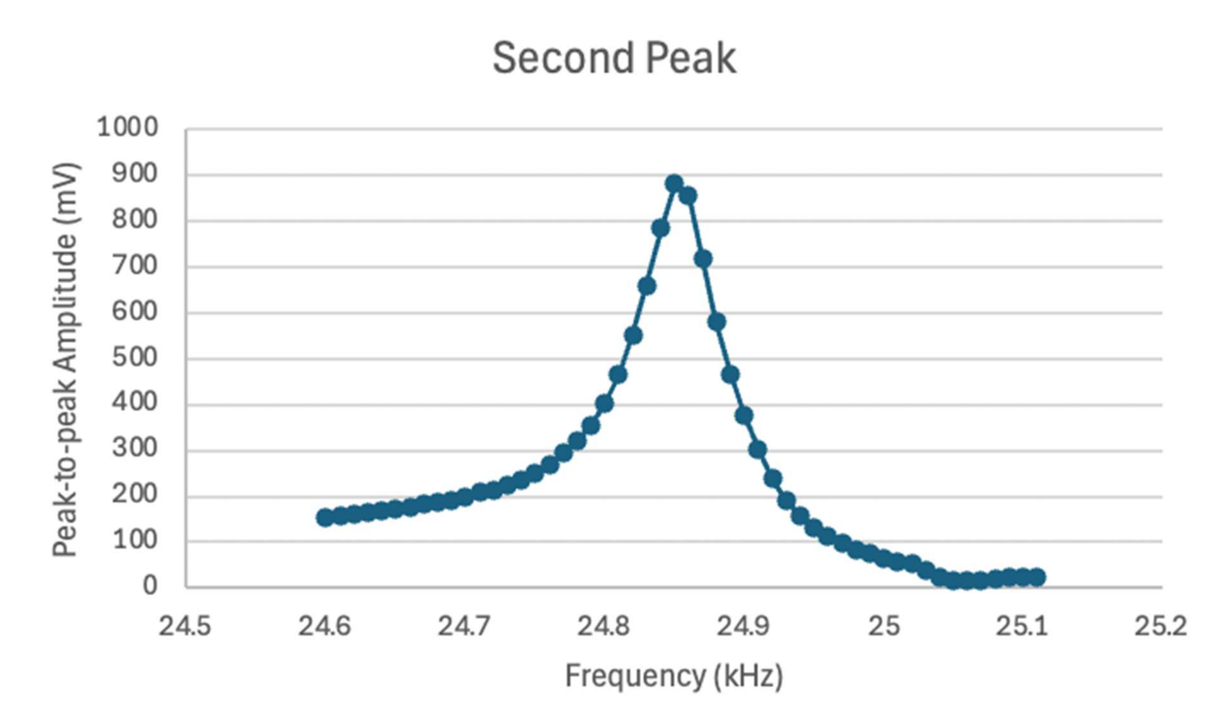

Fig. 24: Second resonance peak from 500 ml large sphere, two PZTs

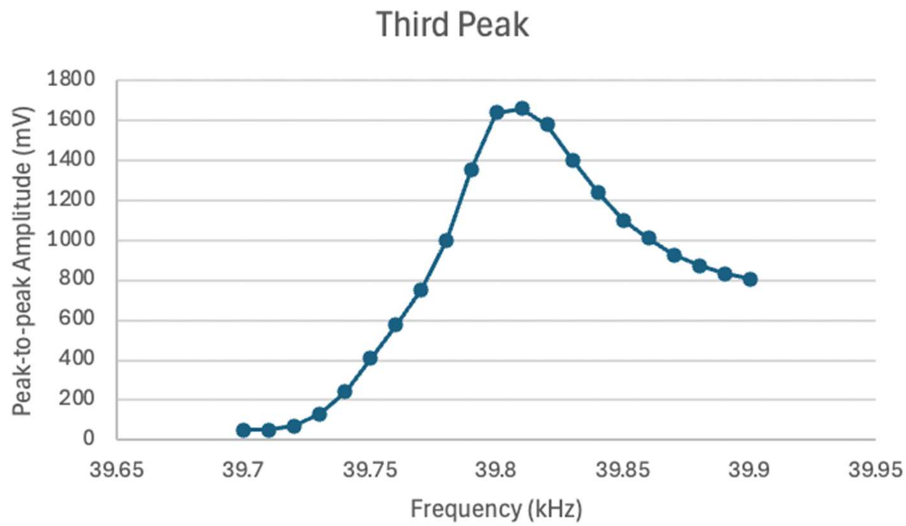

Fig. 25: Third resonance peak from 500 ml large sphere, two PZTs

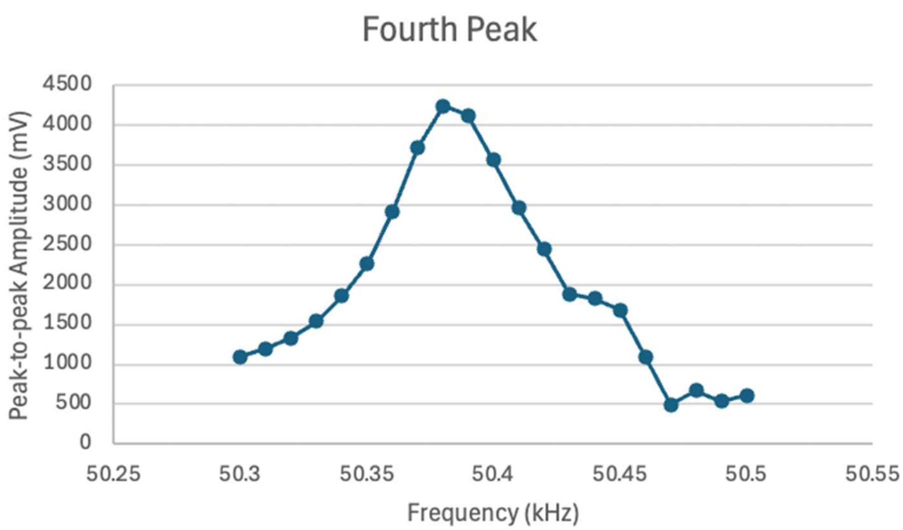

Fig 26: Fourth Resonance peak from 500 ml large sphere, two PZTs

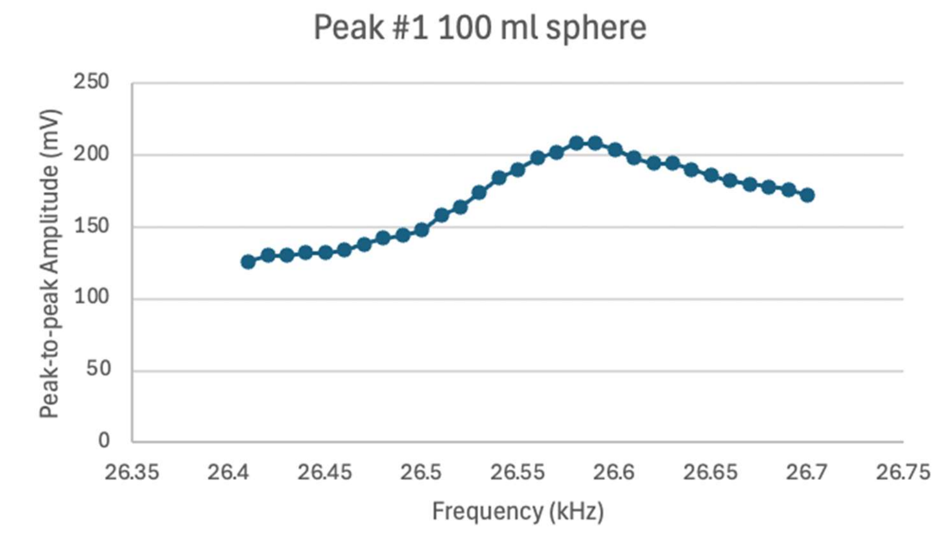

Fig. 27: First resonance peak of clear neck, 100ml small sphere, two PZTs

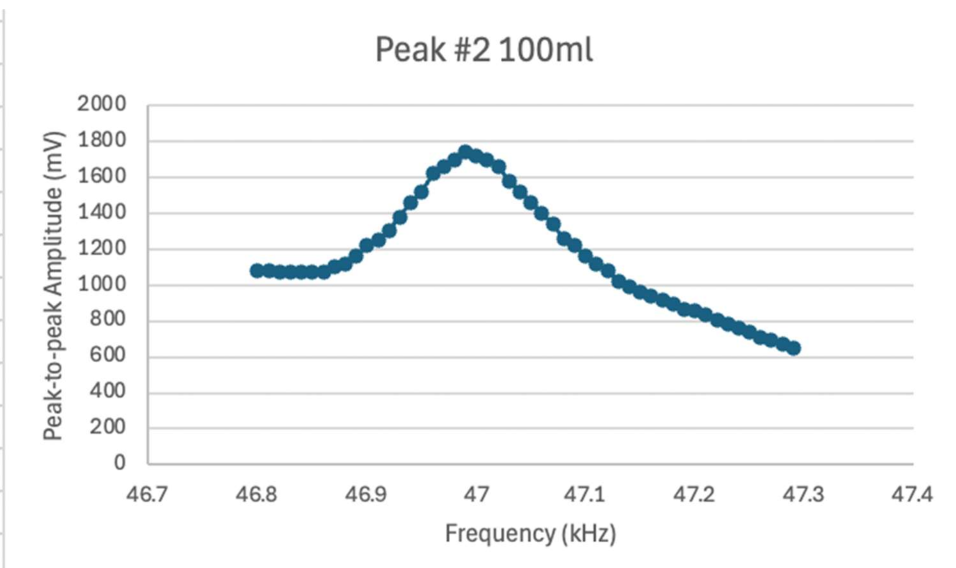

Fig. 28: Second resonance peak of clear neck, 100 ml small sphere, two PZTs

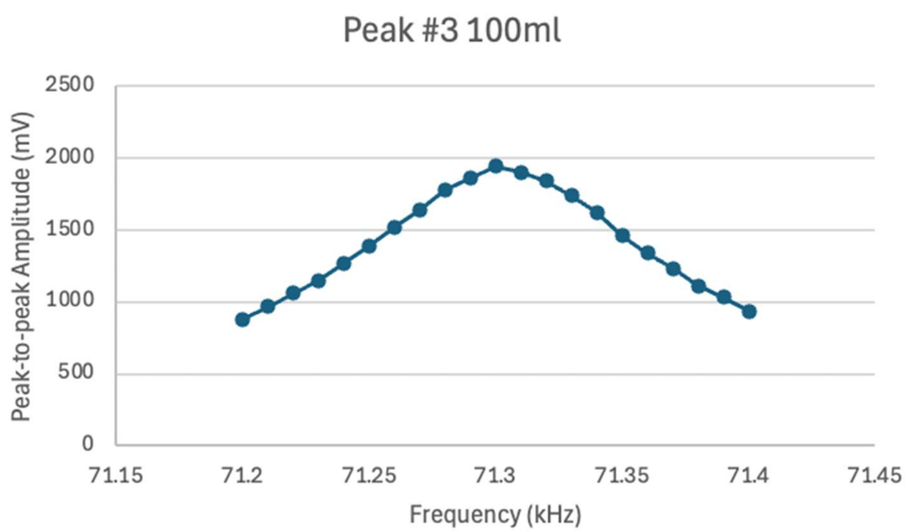

Fig. 29: Third resonance peak of clear neck, 100 ml small sphere, two PZTs

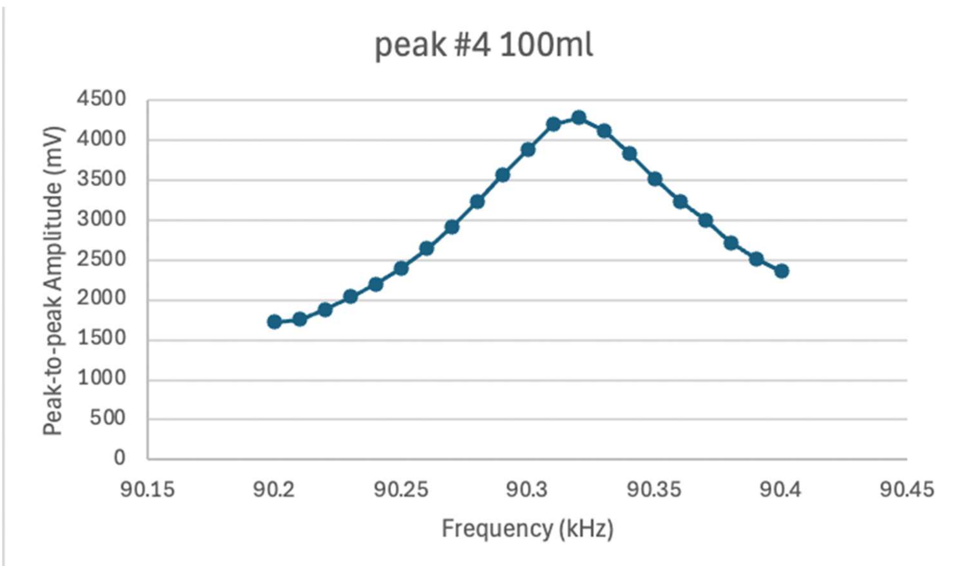

Fig. 30: Fourth resonance peak of clear neck, 100 ml small sphere, two PZTs

Group 2:

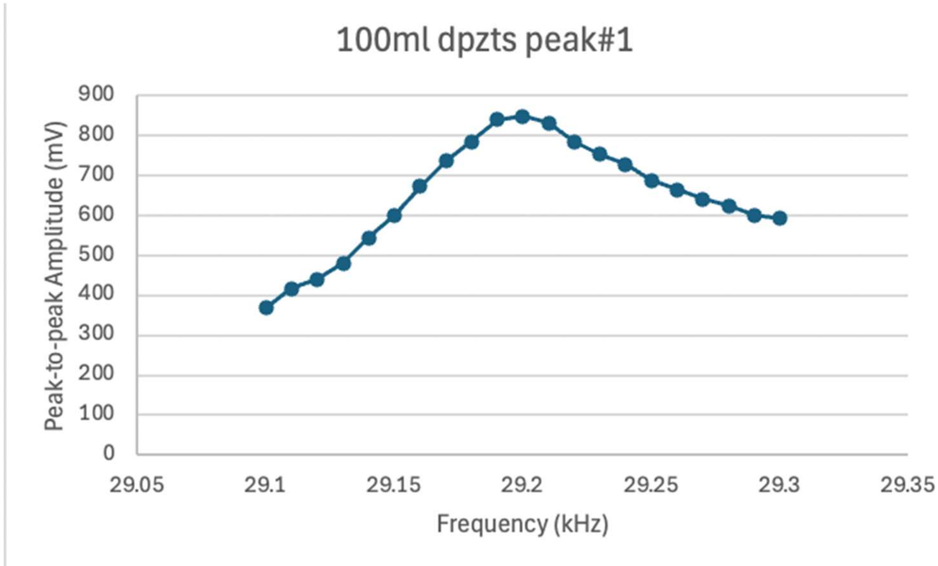

Fig. 31: First resonance peak of opaque neck, 100 ml sphere, two PZTs

Shifted about three kHz compared to the clear neck 100 ml sphere.

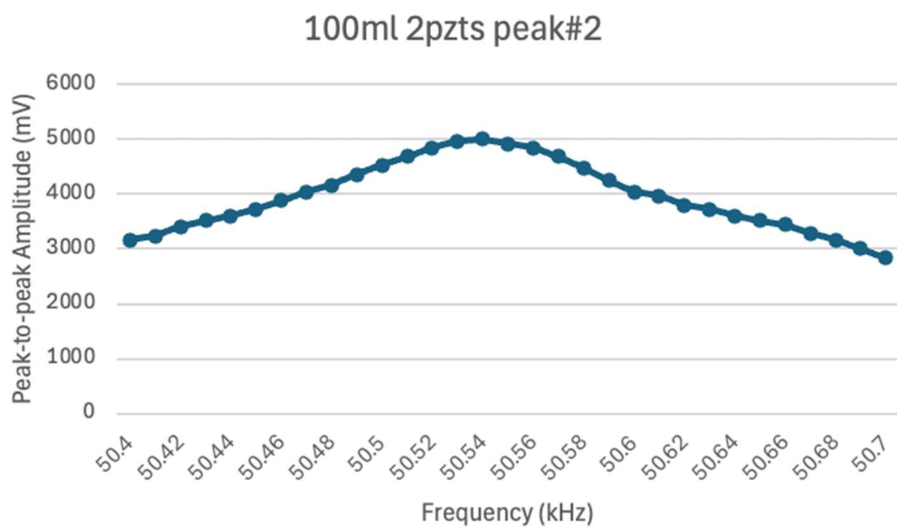

Fig. 32: Second resonance peak of opaque neck, 100 ml sphere, two PZTs

Shifted resonance peak upwards compared to the clear neck 100 ml sphere. This upward shift in resonance may be caused by the “shoulders of the opaque neck flask.

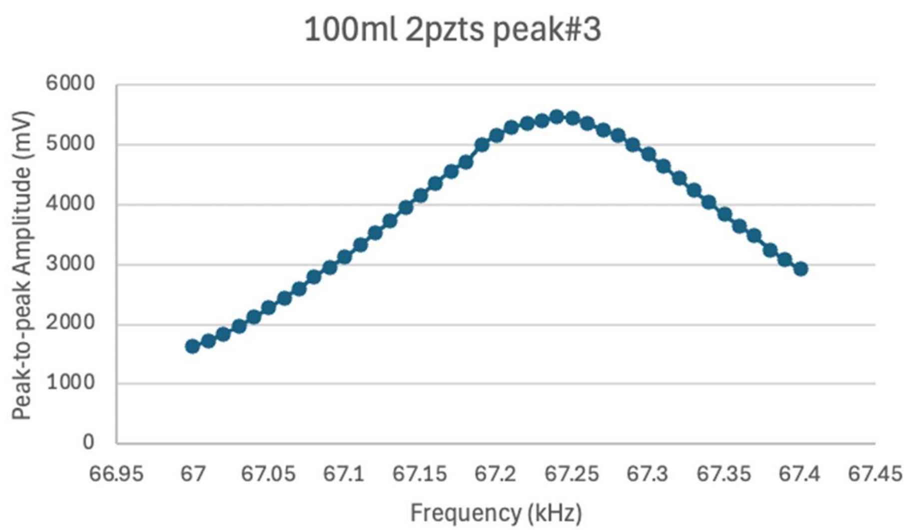

Fig. 33: Third resonance peak of opaque neck, 100 ml sphere, two PZTs

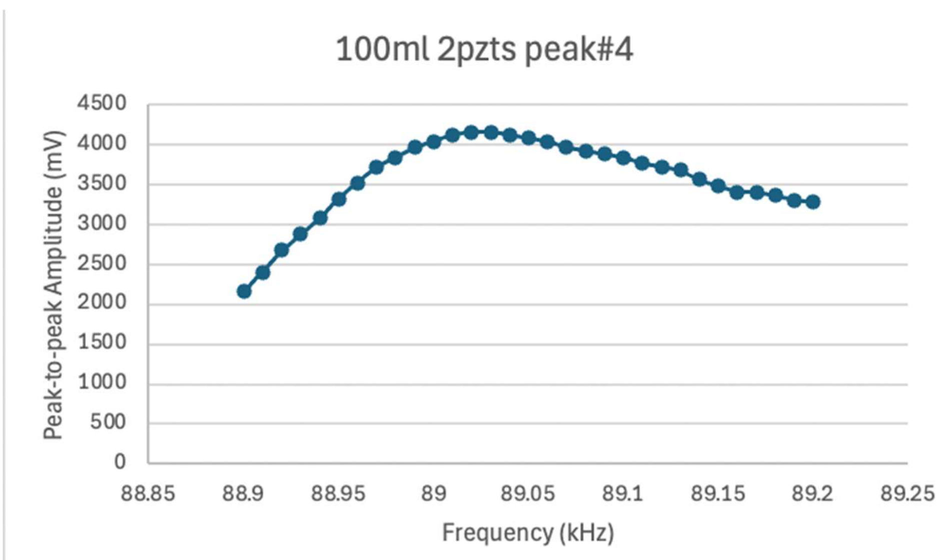

Fig. 34: Fourth resonance peak of opaque neck, 100 ml sphere, two PZTs

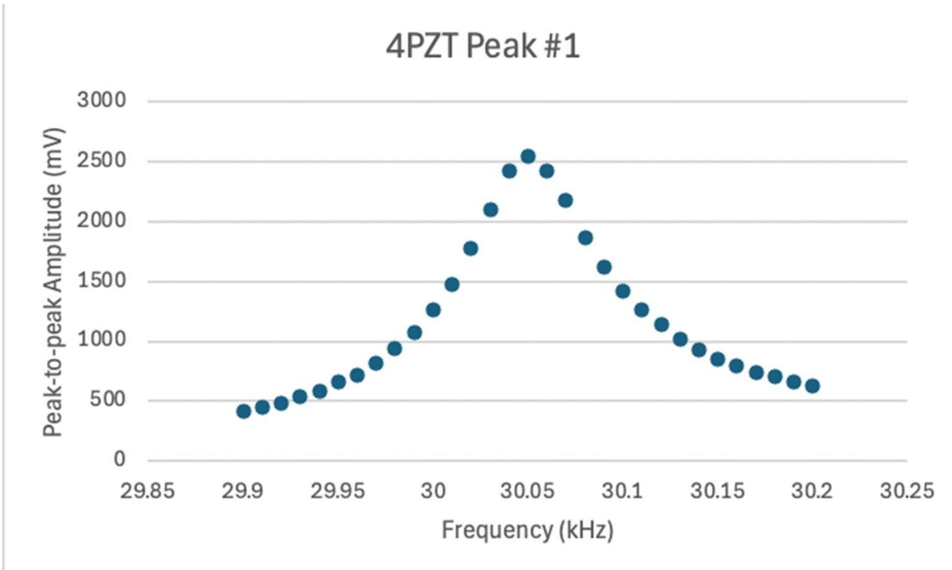

Fig. 35: First resonance peak of opaque neck, 100 ml sphere, four PZTs

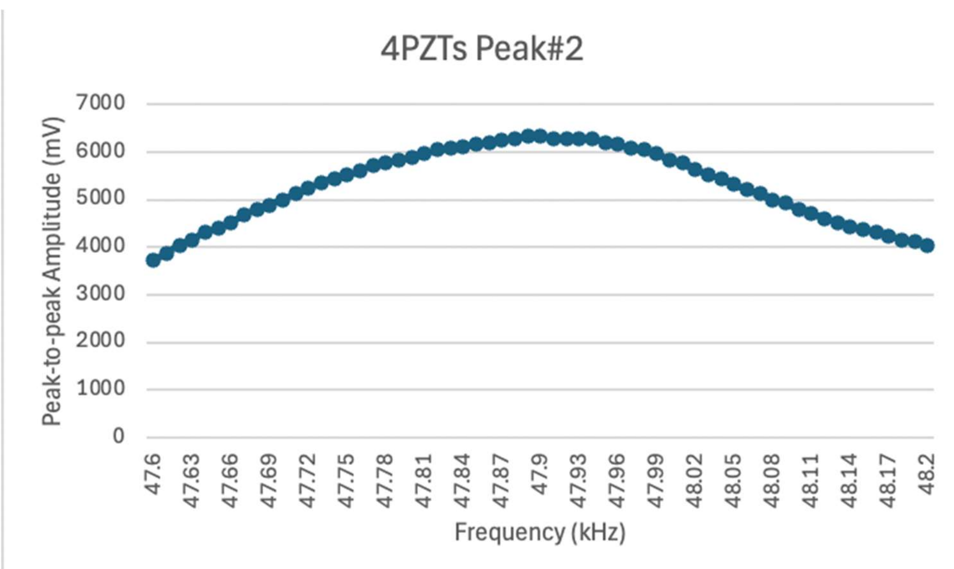

Fig. 36: Second resonance peak of opaque neck, 100 ml sphere, four PZTs

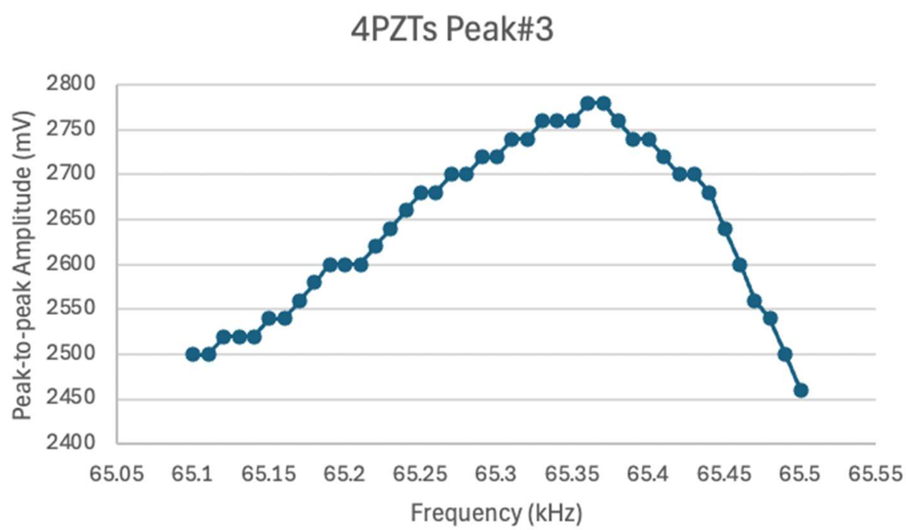

Fig. 37: Third resonance peak for opaque neck, 100 ml sphere, four PZTs

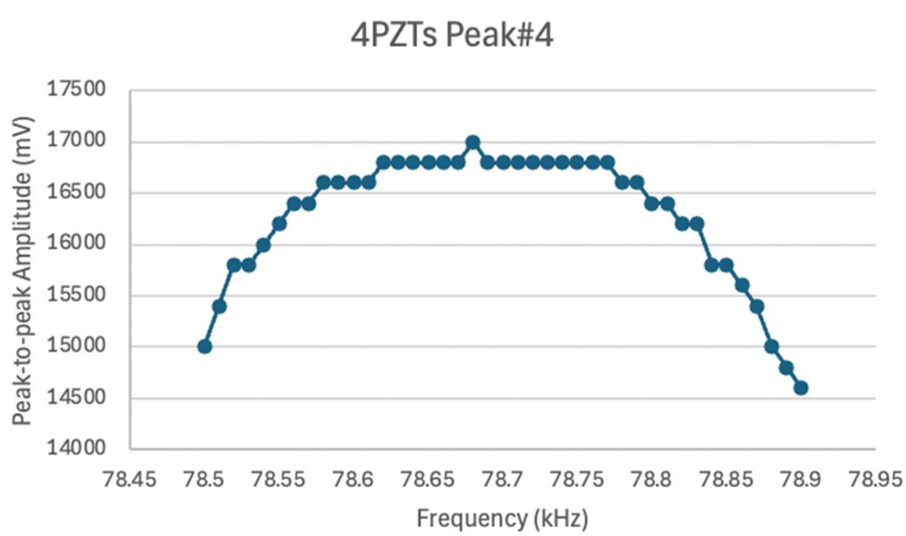

Fig. 38: Fourth resonance peak for opaque neck, 100 ml sphere, four PZTs

Group 3:

For group three, the cylindrical vessels had insufficient resonance peaks below the second calculated resonances for each cylindrical vessel to take data for the focused spectra. This is possibly because the energy of the lower resonance frequencies is absorbed/dissipated in the acrylic material. So, for group three, the focused data spectra were taken from the second calculated resonance and up, focusing on the odd calculated resonances for data collection.

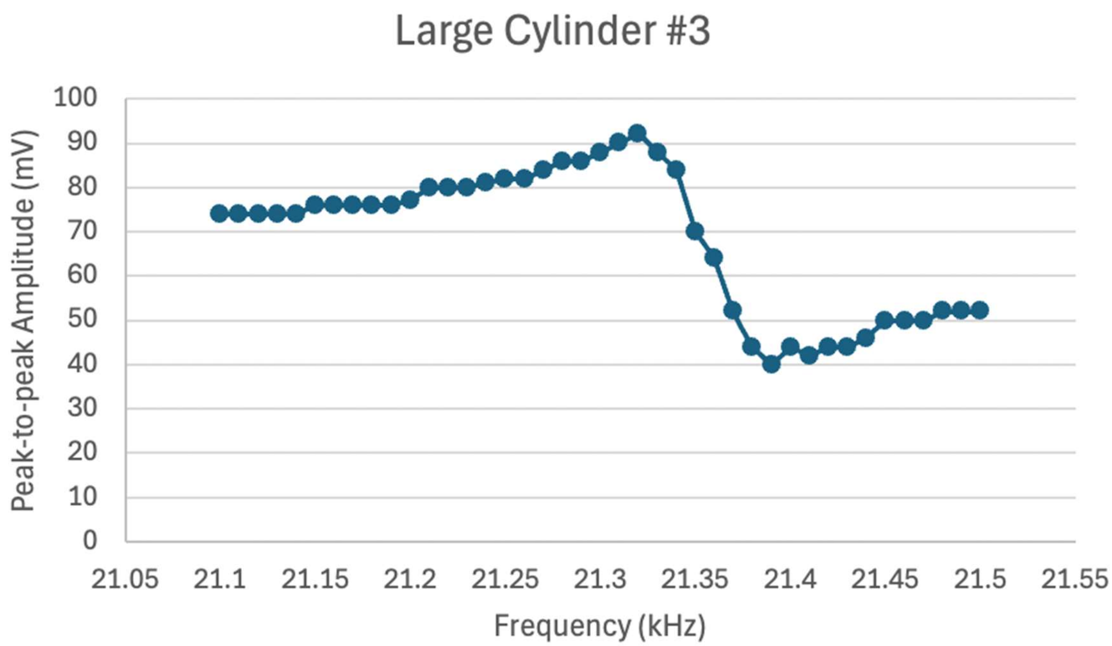

Fig. 39: Third resonance peak for large cylinder, one PZT

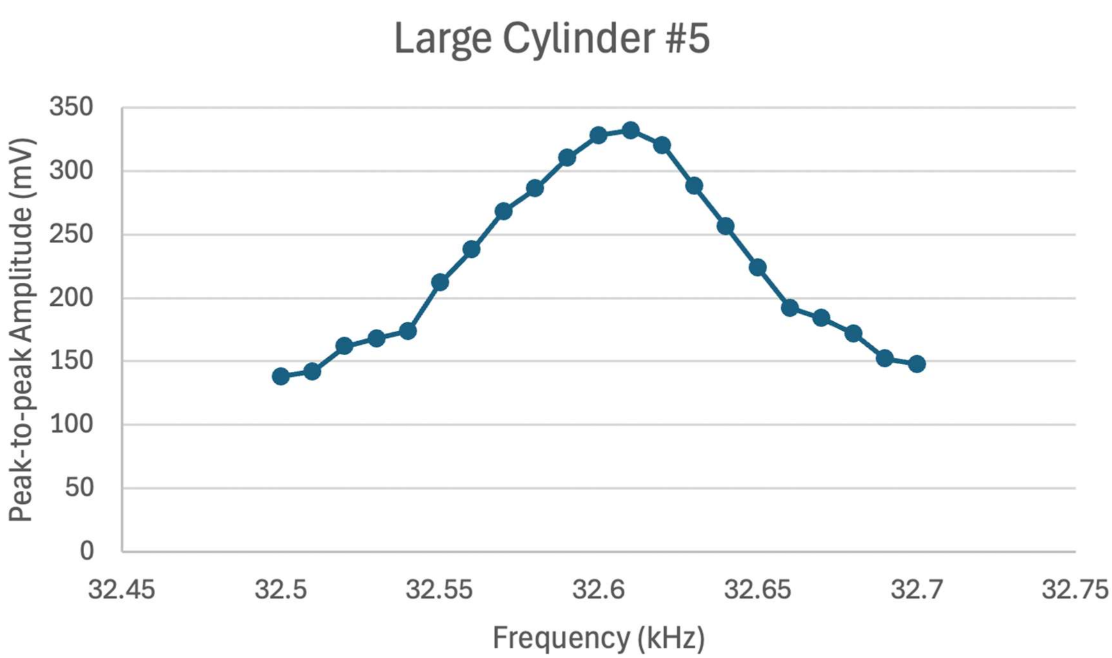

Fig. 40: Fifth resonance peak for large cylinder, one PZT

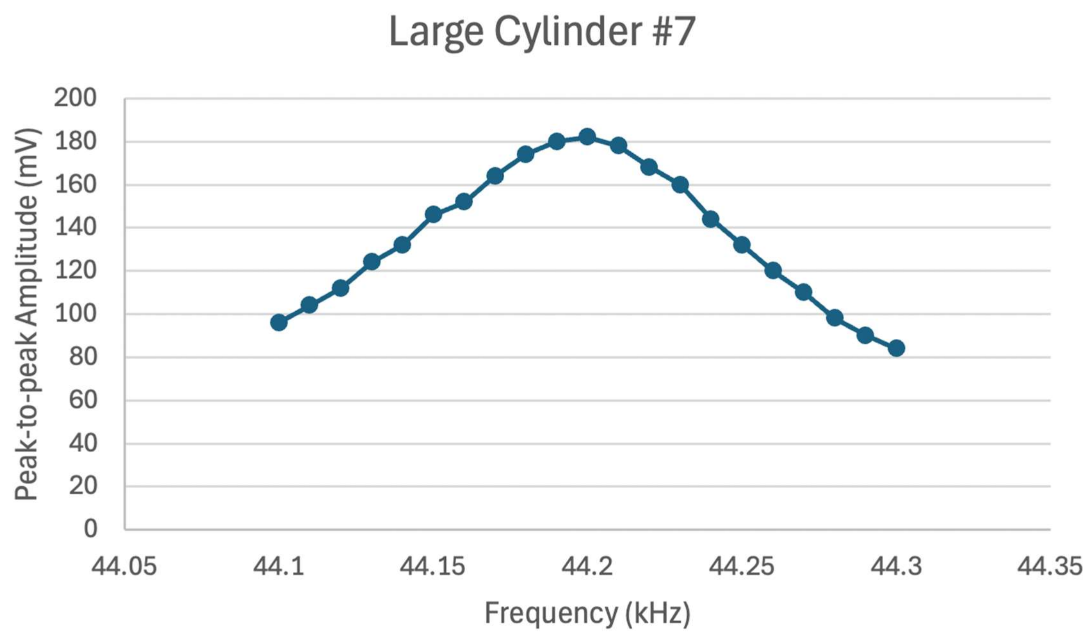

Fig. 41: Seventh resonance peak of large cylinder, one PZT

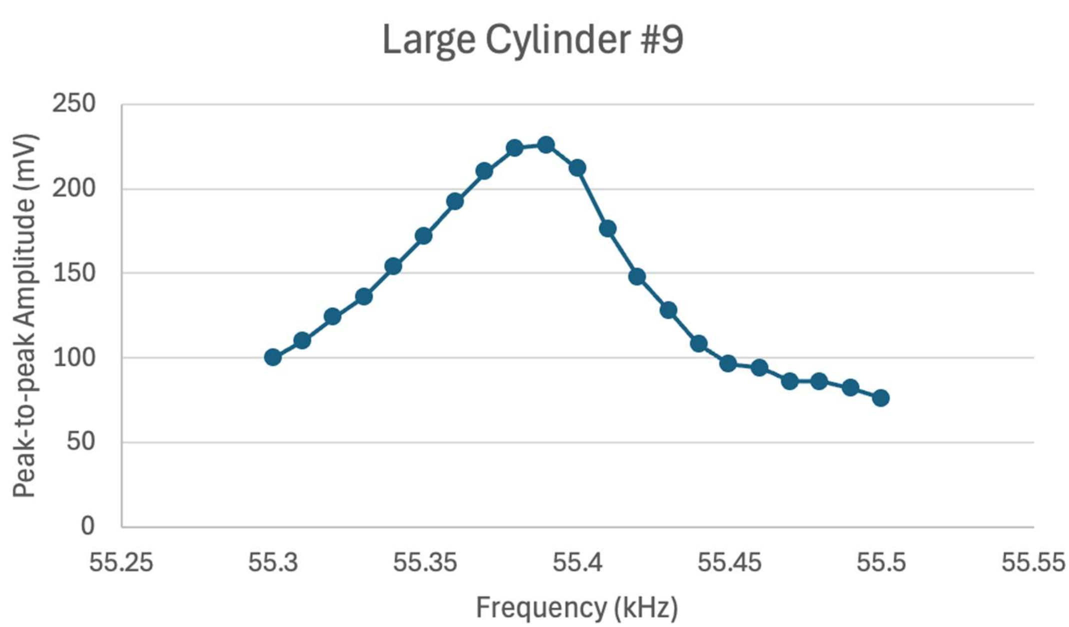

Fig. 42: Ninth resonance peak for large cylinder, one PZT

The ninth resonance peak is not shown in table 1 of the calculated resonances for the large cylinder, but can be calculated by multiplying the first calculated resonance by nine since n=9.

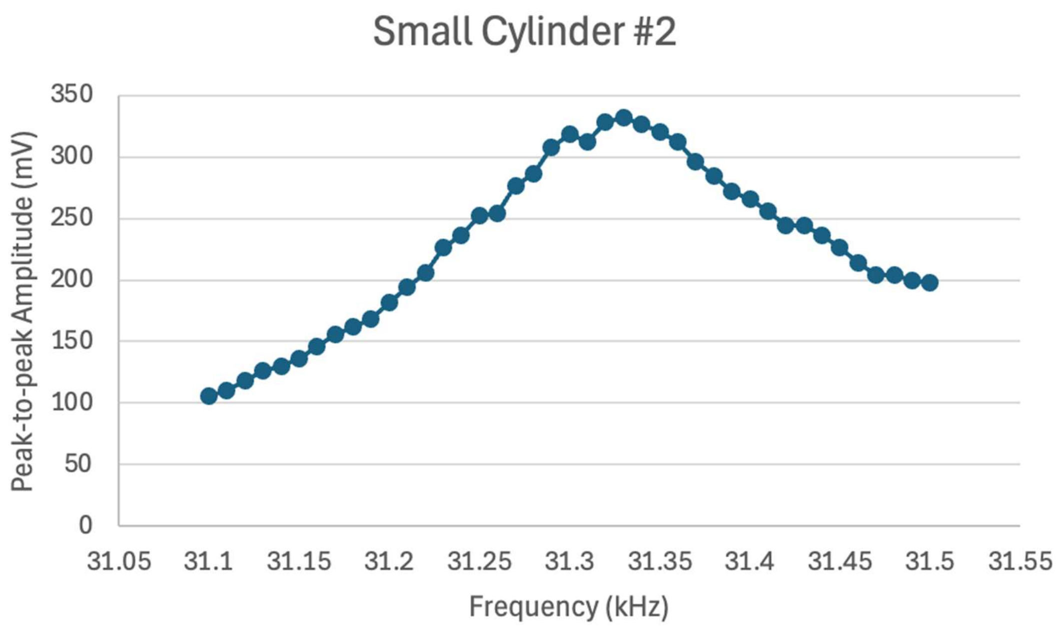

Fig. 43: Second resonance peak for small cylinder, one PZT

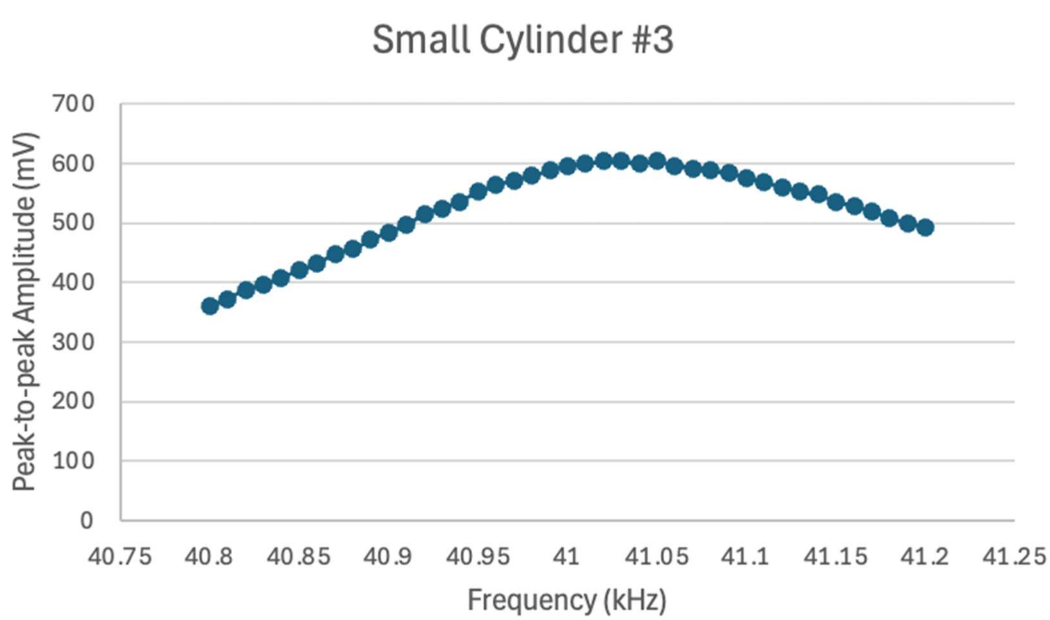

Fig. 44: Third resonance peak for small cylinder, one PZT

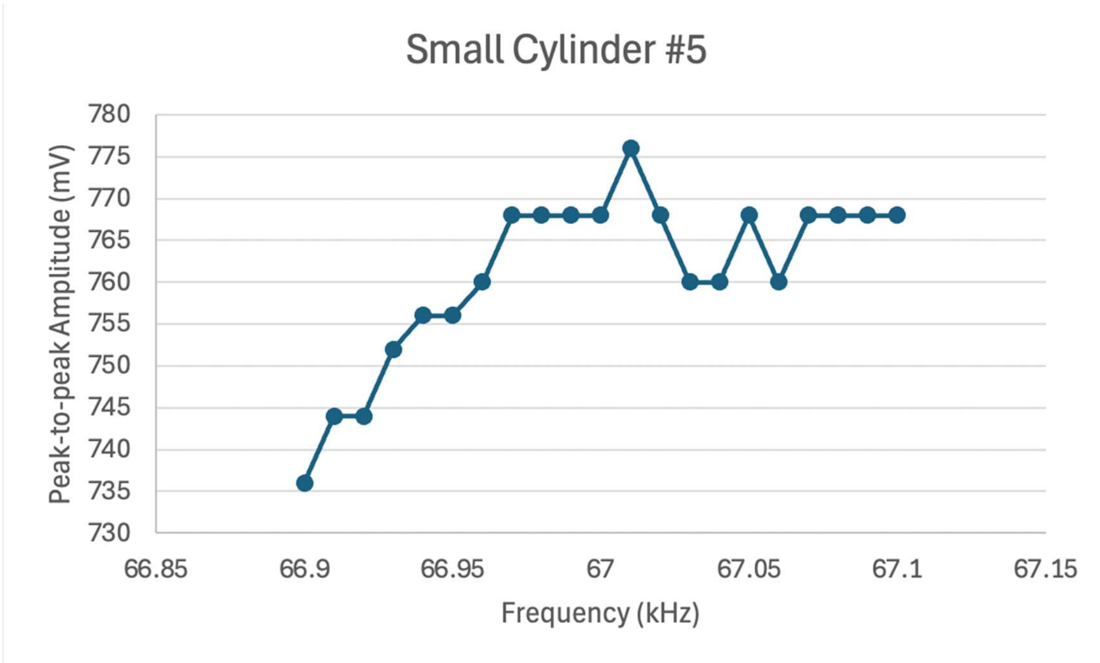

Fig. 45: Fifth resonance peak for small cylinder, one PZT

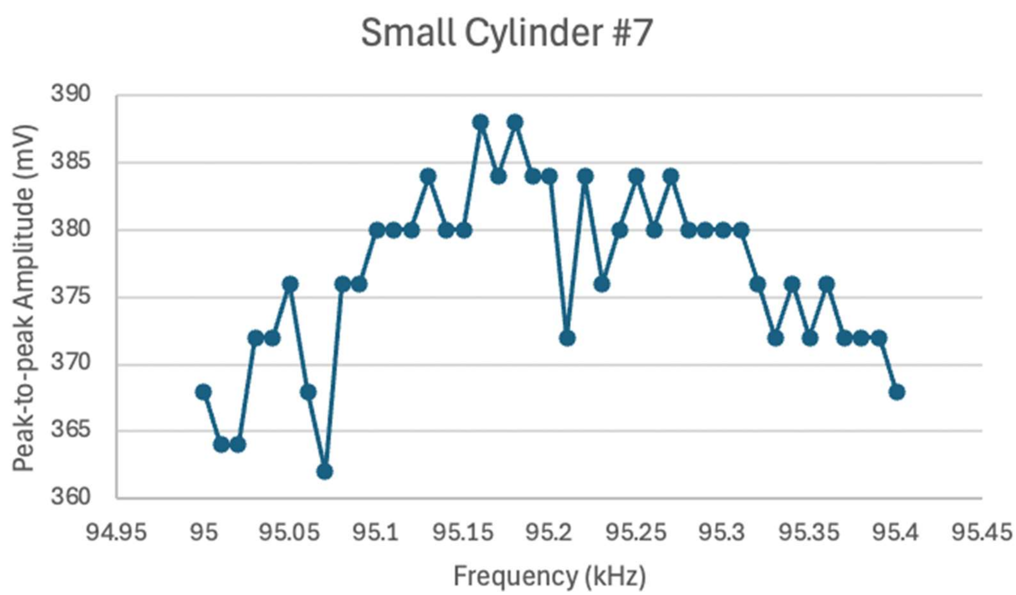

Fig. 46: Seventh resonance peak for small cylinder, one PZT

Data Analysis:

Starting with the broad spectra, in group 1, which is composed of the large sphere and the clear neck, small sphere with two PZTs, figure 13 and 14. The resonance peaks are taller in the smaller sphere than the larger one. This may be due to the size difference that causes the resonances in the smaller sphere to be at higher frequencies than the larger sphere. The fundamental resonance frequency for the large sphere was calculated to be around 12.5 kHz. In the broad spectra, a significant peak cannot be seen until around 24 kHz. In acoustic resonators, the fundamental is expected to be the strongest, but the broad spectra suggest otherwise. This is the same for the small sphere as the calculated fundamental resonance frequency was calculated to be about 26.5 kHz, but a significant resonance spike doesn't appear on the broad spectra until around 45 kHz. This may be due to the larger energies associated with the higher frequencies and their ability to excite multiple modes or energy transfer between modes.

For group 2, the spheres were the same size at 100 ml with a diameter of 5.5 cm and an opaque neck with "shoulders" connecting the neck to the body, shown in figure 8 and 9. One sphere had two PZTs and the other had four PZTs. Both of the broad-spectra graphs were very similar, shown in figure 15 and 16. The two PZT sphere had "sharper" resonance peaks compared to the four PZT sphere. The first definitive peak that can be seen on the graph for the two PZT sphere is at around 28 kHz. For the four PZT sphere, it is around 30 kHz. This 2 kHz shift in the fundamental resonance frequency could result from one of the spheres having two extra PZTs, adding mass to the equatorial region of the flask as well as changing the driving fluid symmetry. It can be seen that the four PZT vessel has larger resonances, where its highest peak-to-peak amplitude is around 17,000 mV compared to the highest peak-to-peak amplitude of the two PZT sphere at around 11,000 mV. The focused spectra of the resonance frequencies are where it gets interesting, which will be discussed later in this section.

In group 3, the broad spectra for both cylinders were not as “sharp” (weak resonance peaks and more noise) as the other groups, shown in figure 21 and 22. This could suggest that there was unknown noise sources not accounted for when setting up the cylinders for data collection. It could also be due to the material difference between the glass spheres and the plastic cylinders (energy may be dissipated more in the acrylic than in the glass). For the large cylinder broad spectra, there is a large and “sharp” peak at around 32 kHz. The resonance peaks produced in the broad spectra of both cylinders likely contain both radial and axial resonance nodes, so it is difficult to pick out which peaks are the radial resonance peaks and which ones are axial resonances or produced from outside noise. This affected how the data turned out for the focused resonance spectra as will be discussed later.

For the focused spectra, all the spherical vessels had similar fundamental resonance peak shapes where it reached a maximum amplitude and then started to go back down, but then leveled off at a higher amplitude in mV than compared to the amplitude it started out before it started to increase. This may be a result of long-term DC drift of the amplifier/function generator system. There is one outlier in this trend and that is with the 100 ml sphere with four PZTs in group 2, figure 35. This fundamental frequency peak had the best Gaussian-like peak shape out of all the vessels in all three groups. This is the desired shape that is created when a strong resonance peak is found. It is similar to a Gaussian curve. Most of the resonance frequency curves produced by the vessels were irregular Gaussian curves. Both the large sphere and large cylinder had good resonance frequency curves for the higher resonances while the small cylinder and small spheres had good resonance curves for the lower resonance frequencies. The four PZT sphere resonances became broader and less Gaussian-like as the frequencies increased, as seen in resonance frequency peaks three and four, figure 37 and 38. The one vessel that had the most inconsistent resonance peaks was the small cylinder. As seen in the focused spectra of the small cylinder, figure 43-46, the shapes of the peaks are not uniform in shape and therefore it is hard to tell if these focused spectra are resonance peaks based on their shapes. Also complicating the spectra for the 5th and 7th resonances are observable ADC levels (resolution of digital read-outs). The broad spectra of the small cylinder has many spikes and it is hard to tell which ones are the resonance peaks we wish to observe and which ones are from noise. This could be from there being both axial and radial resonances for cylinders. A different test focusing more on one type of resonance may be needed to collect stronger data. When going to the higher frequencies, one can see there is not a Gaussian shape at all and the amplitudes are variable. This is interesting because for cylinders, the resonance frequencies will be better for SBSL if the diameter and the height of the cylinder are different, separating the axial modes from the radial modes. This is strange since the small cylinder has a height of 12 cm and a diameter of 5.5 cm. This cylinder should produce good radial resonance frequency peaks but appears not. This may be from complications due to the higher-order axial modes interfering with lower-order radial modes. On the other hand, the large cylinder spectra should be complicated since its height (axial resonances) and diameter (radial resonances) are the same at 12 cm. This is not observed according to the data since the large sphere produced good resonance peaks while the small sphere did not. This may be because the radial and axial modes overlap and both contribute to the resonance spectrum. Taking into account both axial and radial modes when calculating resonance frequencies may produce stronger and consistent data.

Error Analysis

With these types of experiments, there comes a number of errors that could have occurred during the construction of the vessels and the experimentation process. Several possible errors arose and should be accounted for while discussing the results. Firstly, the voltage amplifier needs time to warm up. If the amplifier is not given enough time to warm up, it can affect the voltage put through to the PZTs, giving unstable drift to the amplitude readings. The next thing is soldering the PZTs and the "Hum" test. If too much heat is applied to the PZTs then they will not function properly. With the "Hum" test, it allows to hear the PZT vibrate, but only limited to the range of human hearing, so, with the "Hum" method, there is no way to tell if the PZT functions at limits higher or lower than the thresholds of human hearing.

The next form of error comes from electronic noise and temporal instability. The oscilloscope can be very sensitive to voltage inputs and outputs. If the function generator is turned on before the voltage amplifier is, or if the voltage amplifier is turned off before the function generator is, it can destabilize the built-in voltage measurements of the oscilloscope, causing the amplitudes being recorded to be vastly different from the actual amplitudes being produced. Lastly, while taking data, the voltage amplifier was turned on for long periods of time. This can cause the voltage amplifier, gain or DC offset to drift due to thermal variations. This could explain why some of the focused spectrum resonance peaks leveled out at a different amplitude after going down from hitting the maximum amplitude of those peaks. Changes in room temperature and pressure over the course of a single measurement will also affect the resonance data. This was not actively controlled.

Conclusion

While the process of obtaining the data presented possible sources of error, the results allowed for some promising conclusions about the effects of the shape and size of a sonoluminescence vessel. The spherical vessels appear to be more effective at producing the fundamental resonance frequency, especially the smaller spheres. This suggests that smaller vessels are better for bubble capturing and producing sonoluminescence. When lower-ordered resonance modes were used, the cylindrical vessels were not as efficient at producing resonance frequency peaks as the spheres, but this could be from errors in the process of collecting, not properly setting up the vessels, or the material difference between the glass spheres and the plastic cylinders.

The most surprising and exciting finding was the small sphere with four PZTs. It was the most effective at producing Gaussian-like resonance frequency peaks, especially at lower resonances. This suggests that adding more PZTs may increase the effectiveness of the vessel at capturing and producing sonoluminescence. This project has explored how size and shape of a sonoluminescence vessel influences its ability and usefulness for sonoluminescence. These findings indicate that there are possible benefits of using specific vessels to analyze and produce sonoluminescence. In this field, most research focuses on the sonoluminescence phenomenon itself, but there is definitely more to discover in this area of physics where we look outside of the bubble.

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