The Natural Frequencies of a Gas Bubble in Compliant Tubes

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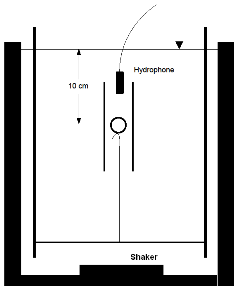


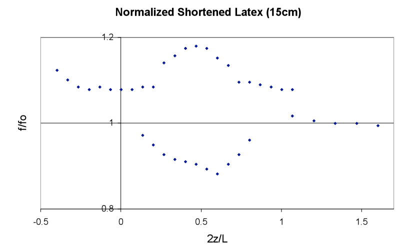
Diagram showing experimental setup. The stainless steel tank is filled with deionized and degassed water. Shaker at the bottom is controlled by a signal generator. The bubble was secured to the top of a modified coat hanger and maintained at a constant depth 10 cm from the surface. A hydrophone was secured from above and maintained a constant position above the bubble. The tube itself was mounted on a 3D position system (not shown) allowing the tube to move independently of the bubble

Problem Statement

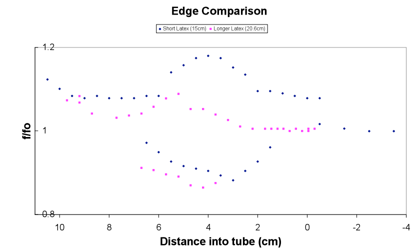
A perfectly spherical free field bubble has one resonant frequency given by the Minnaert equation (Minnaert, 1933). A bubble in a rigid tube has a depressed natural frequency that can be described by a model presented by Oguz and Prosperetti, 1998. For potential medical applications, such as drug delivery through micro-bubble injection, it is important to know the effect that a compliant tube has on the resonant frequency of a bubble. Through experimental results it has been found that a bubble in a compliant tube can have up to 2 resonant frequencies with one frequency being above the free field frequency.

Method

Bubbles were modeled with fingercots (balloons) inflated to 60 cm gauge pressure of water. The balloons were then placed at various positions within a compliant tube and the frequency of a shaker at the bottom of the tank was swept from 100 Hz to 600 Hz. A hydrophone above the bubble recorded the pressure output and the peak response was recorded as the resonant frequency. In the case of two distinct peaks on a frequency sweep both peaks were recorded as resonant frequencies.

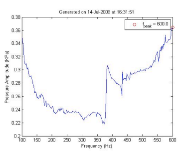


Plot of the natural frequencies for a shorter latex tube. f is the resonant frequency and fo is the free field frequency of the bubble

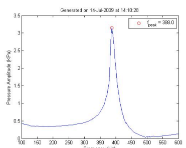


Shows comparison between shorter and longer latex tubes. The x axis shows distance of the bubble from the edge of the tube where positive distances are farther into the tube.

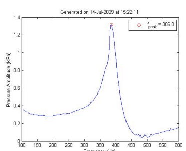
Frequency Sweeps: PVA tube



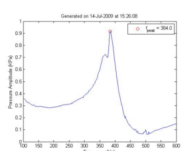
Profile of the tank and testing rig



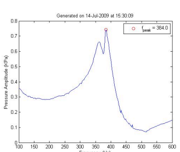
Free Field Bubble



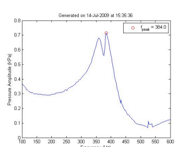
Bubble ½ in Tube: 1.02 (on scale of 2z/L)



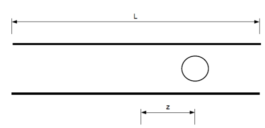
Fully In Tube: .88



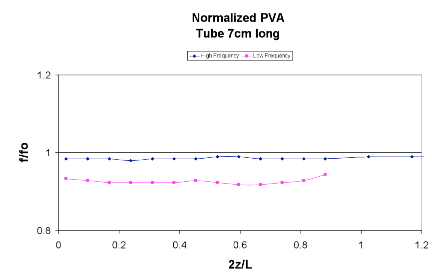
Still Further in: .81



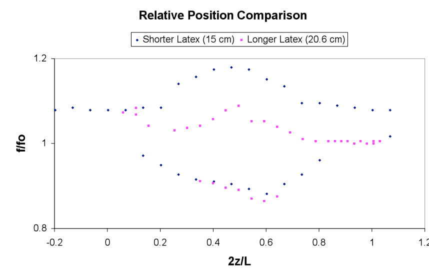
Even Further In: .74



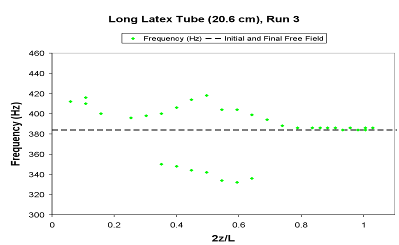
Shows schematic for bubble relative positioning within the tube. L is the length of the tube and z is the distance from the bubble midpoint to the center of the tube



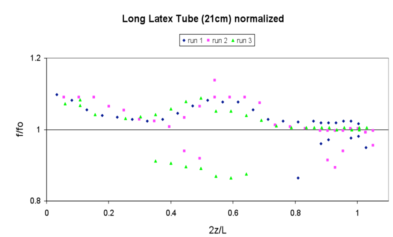
Resonant frequency relative position vs relative position in a polyvinyl alcohol tube. The PVA tube had a Young's Modulus of around 170 kPa. The tube was also much shorter (7 cm) then either of the other latex tubes (15 cm and 20.6 cm)



Shows comparison between the shorter and longer latex tubes, where bubble position is measured by relative position within the tube.



Shows the resonant frequencies for every location of the bubble during testing on the long latex tube 20.6 cm. On the 2z/L scale 1 represents the bubble midpoint being at the edge of the tube and 0 represents the middle of the tube



Plot of runs with three different bubbles on the longer latex tube. f is the resonant frequency and fo is the free field frequency of the bubble

Conclusions

Compliant tubes deviate from the results expected for the resonant frequency of a bubble in a stiff tubes. In compliant tubes it is possible for a bubble to have two resonant frequencies. One mode possibly dominated by bubble motion and the other by tube motion. Further research is needed to observe the different modes. Unlike rigid tubes the principle resonance of a bubble in a compliant tube can be above its free field resonant frequency. Future tests are needed on softer tubes with modulus in the range of 5-25 kPa, similar to that of soft tissue. Tests also needed to be conducted with smaller bubbles and trials need to be run with they hydrophone to in a variety of positions within the tube to account for effects from just the tube.

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Mechanical Engineering, 2010