Simulation Studies on the Design of a Helmholtz Resonator Type Underwater Acoustic Sensor

Karthi Pradeep[1], Suresh G.[2], Natarajan V.[2]
1. National Institute of Technology, Tiruchirappalli, Tamil Nadu, India
2. Naval Physical & Oceanographic Laboratory, Kochi, Kerala, India

Introduction: A Helmholtz resonator type acoustic sensor has been designed for underwater operation at 10kHz. The sensor consists of an aluminium double frustum cavity, hour-glass shaped, with the resonator at the bottom and a horn above to amplify the incoming acoustic signal, Fig.1. The resonator provides a narrow band amplification, whereas the horn provides broad band amplification. The frequency of resonance of the Helmholtz resonator depends only on its dimensions, which are very small when compared to the wavelength of operation. Studied the effects of geometries and dimensions of the acoustic sensor for its amplification, resonance frequency, etc. The effect of materials characteristics in the fabrication of the device was also studied.

A Helmholtz resonator consists of a rigid walled cavity of volume V with a neck of area A and length L. When excited by an acoustic input, a single resonance is observed, whereby the acoustic pressure is amplified to a high level within the cavity. This frequency of resonance is given by the equation:

$$f = \frac{c}{2\pi}\sqrt{\frac{A}{LV}}$$

Computational Methods: The design parameters of the device – diameter of base, diameter of neck, height of the resonator were optimized by analytical and modelling studies. Fig. 2 shows the model geometry used in COMSOL Multiphysics. The Pressure Acoustics interface in the Acoustics Module is used. The boundary conditions of the structure were specified in terms of acoustic impedance of the walls of the structure. The entire structure was fine meshed uniformly using tetrahedral elements. An input acoustic pressure of 1MPa was applied at the opening of the horn.

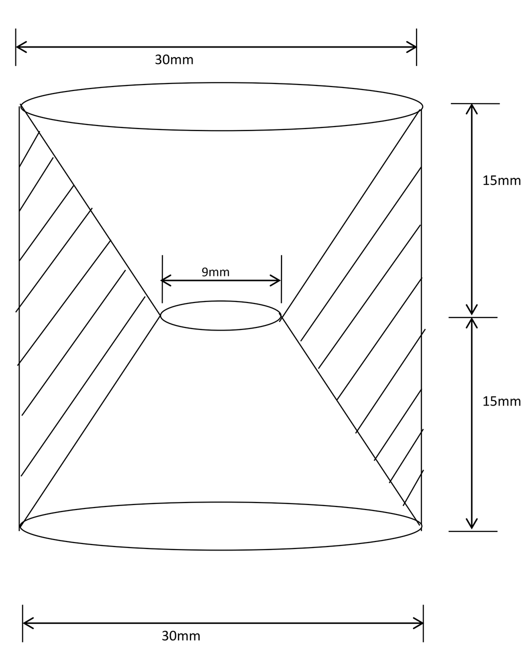

Figure 1. Helmholtz resonator type acoustic sensor

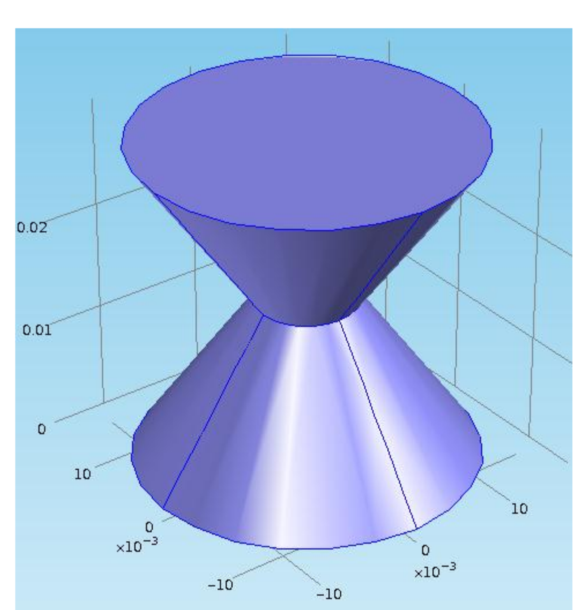

Figure 2. Model used in FEM analysis using COMSOL

Results:
The analytical and simulated results of the resonant frequency are nearly same.

- The frequency obtained by simulation was 8.85kHz. The difference could be attributed to the end correction factor that was not included in the neck length in the analytical method.
- The variation of resonant frequency of the cavity with the depth of the cavity was also investigated, Fig.3. It was seen that the frequency of resonance decreases with increasing depth of cavity with all other parameters constant.
- The acoustic pressure variation along the structure showed that pressure increases towards the base of the resonator, Fig.4 & Fig.5. Also the pressure increased from the centre towards the walls of the resonator cavity, while it decreased towards the walls inside the horn, Fig.6.
- The amplification obtained at resonance depends on the acoustic impedance of the material used to fabricate the structure. For materials with higher impedance, the amplification will be greater.
- The thickness of the cavity walls also influences the resonance.

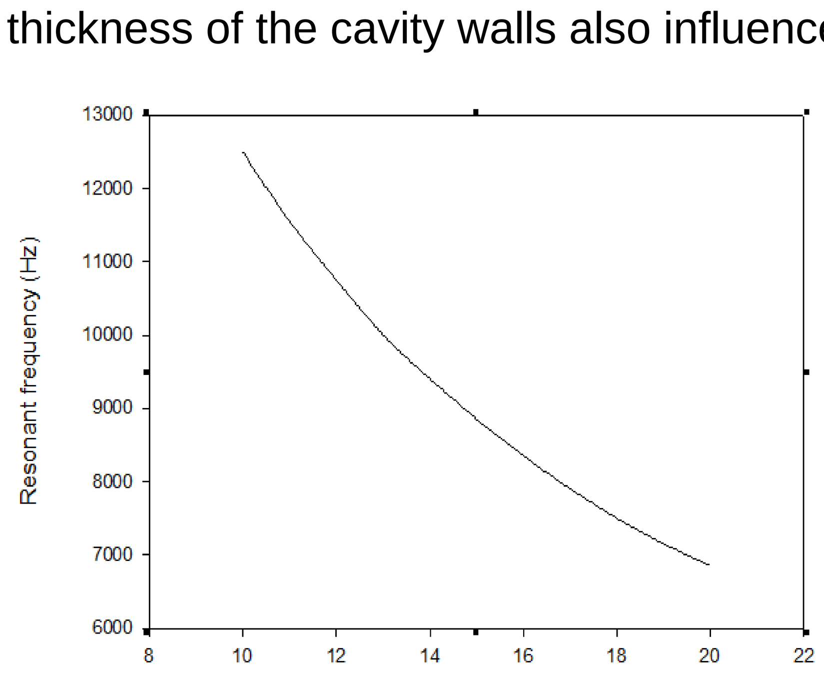

Figure 3. Variation of resonant frequency with the depth of cavity

The base angle of the resonator cavity also influences the acoustic pressure distribution at resonance. In MEMS fabrication of such a device using Silicon wafer, this angle corresponds to 54.7 degrees due to anisotropic etching characteristic that depends on the orientation (plane) of silicon wafer.

The amplification due to the horn is proportional to the ratio of the openings of the horn.

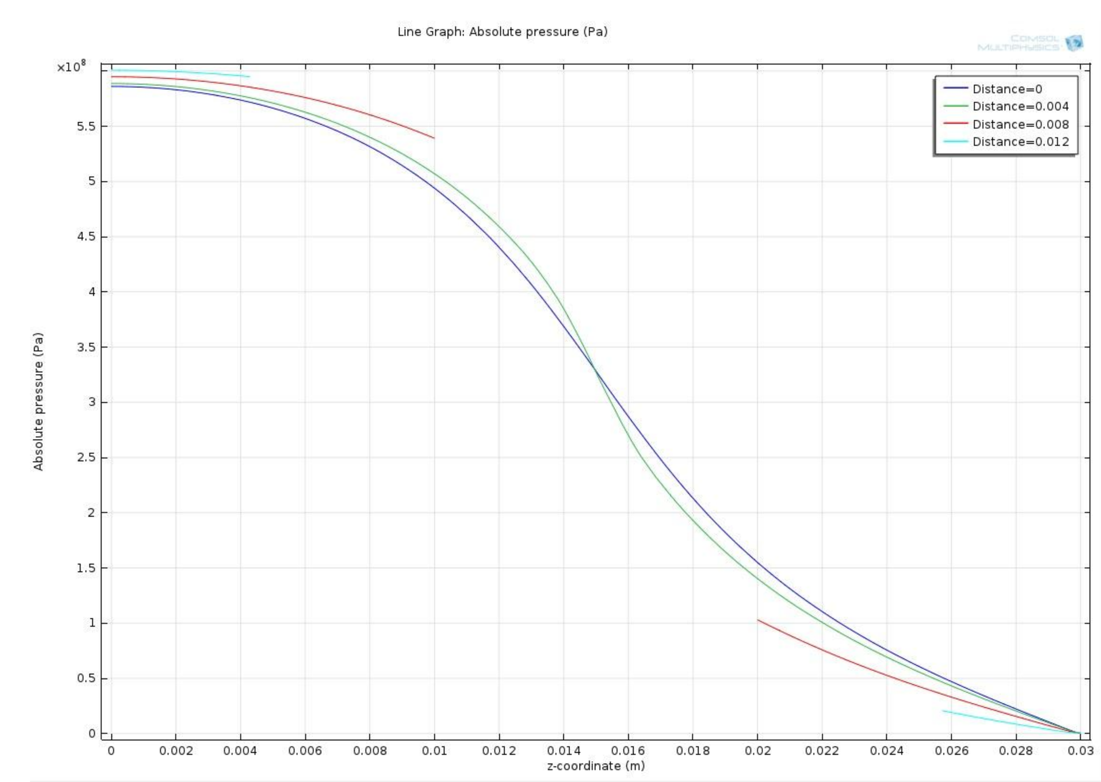

Figure 4. Acoustic pressure variation along the axes of structure

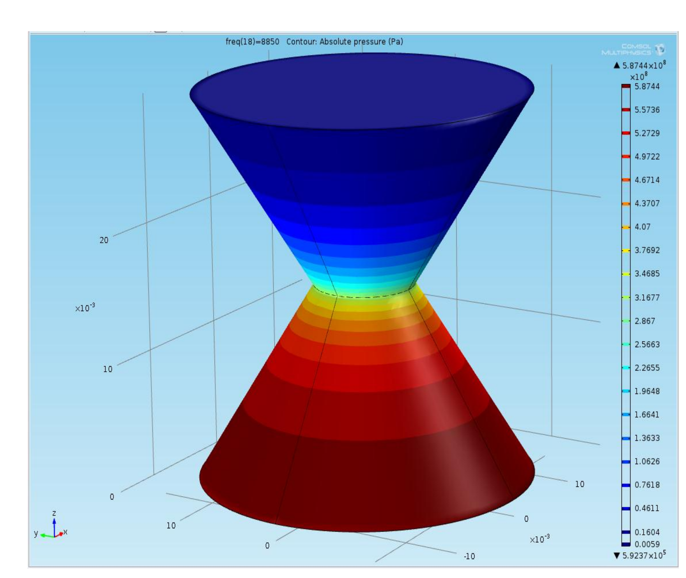

Figure 5. Contour plot of the Acoustic pressure inside the cavity at resonance

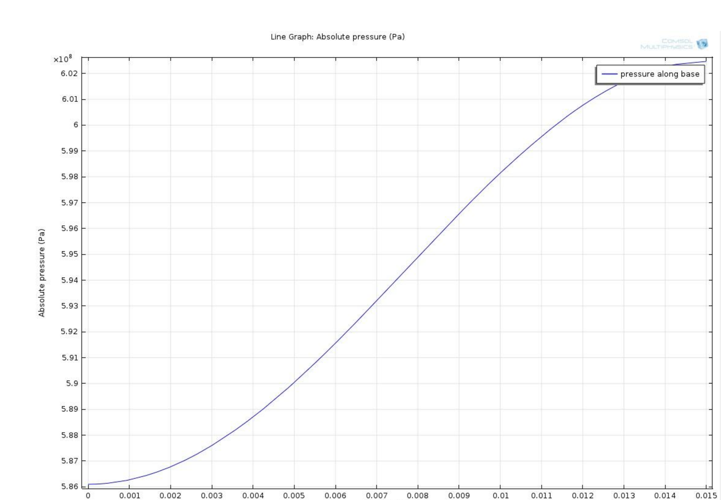

Figure 6. Acoustic pressure variation along the base (resonator)

Analytical frequency	Simulated frequency	Amplification at resonance
10 kHz	8.85 kHz	580

Table 1. Results obtained using FEM

Conclusions:
- This structure can be used as an underwater acoustic sensor.
- A thin piezoelectric disk, PZT-5H, placed at the base of the resonator structure can sense this acoustic pressure variations and convert the acoustic energy into electrical energy.
- The effect of aluminium nitride coating on the aluminium structure to reduce oxidation when immersed in sea water is being investigated.

References:

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