Simulation of Acoustic Energy Harvesting Using Piezoelectric Plates in Quarter-Wavelength Straight-Tube Resonators

B. Li[1], J. H. You[2]

[1]Southern Methodist University, Dallas, TX, USA
[2]Southern Methodist University, Dallas, TX, USA

Abstract

An acoustic energy harvesting mechanism using piezoelectric plates placed inside quarter-wavelength tube resonators has been studied numerically using COMSOL Multiphysics 4.3. Although there are numerous research activities focusing on harvesting various environmental energies, acoustic energy harvesting has seldom been studied. Acoustic energy is clean, ubiquitous, and sustainable in our life, so it is a good candidate for an alternative energy resource. In this study, as shown in Figure 1A, an open-ended quarter-wavelength straight-tube resonator is used to collect travelling acoustic waves at low frequencies (100~300Hz). Piezoelectric parallel bimorph plates made of Lead Zirconate Titanate (PZT) are placed inside the resonator. At the resonance of the tube, amplified resonant acoustic standing waves are developed inside the tube. Then, the pressure difference (p, Figure 1B) between each side of the plates drive the vibration motion of piezoelectric plates, resulting in the generation of electrical power via the direct piezoelectric effect. In COMSOL, the 3D Acoustic-Piezoelectric physics has been used for a frequency domain analysis.. Background acoustic pressure is used to simulate an incident plane wave which acoustically excites the straight-tube. The tube is made of 0.5" thick polycarbonate plates. The material properties and thickness of tube are also included in simulations to consider sound leakage through tube walls. The calculated pressure amplification factor of a 42cm long quarter-wavelength tube is 105 at 199Hz, which matches well with our experimental result (97 and 199Hz). The resonance behavior of the tube with the presence of piezoelectric plates has been studied. When a single piezoelectric plate is placed and moved from the tube inlet to the tube end, the displacement and output voltage decrease gradually. When multiple piezoelectric plates are placed inside the tube resonator, the interaction between air particle motion and the piezoelectric plates plays an important role in determining the amount of harvested acoustic power. The effect of plate positions, inter-distance between plates, plate size, and cross-sectional areas of tube have been studied to find the optimal acoustic energy harvester design. The calculated results will be compared with our experimental data. In conclusion, a novel acoustic energy harvesting mechanism using piezoelectric plates placed inside quarter-wavelength resonators has been introduced and studied. In order to find the optimal design, the numerical studies of acoustic resonance behavior of tube resonators with piezoelectric plates are performed using COMSOL Multiphysics. The harvested voltage and power have been calculated and compared with experimental data.

Figures used in the abstract

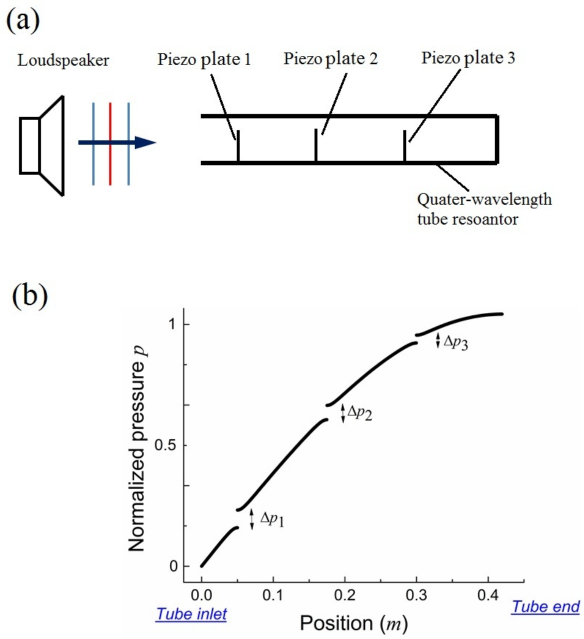

Figure 1: (a) Schematic drawing of acoustic energy harvesting mechanism using piezoelectric plates placed inside quarter-wavelength straight-tube resonator. (b) Calculated pressure inside tube with presence of three piezoelectric plates using COMSOL Multiphysics.

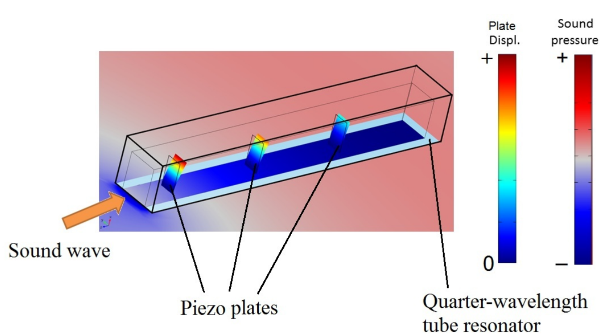

Figure 2: Multiple piezoelectric plates excited by amplified resonant standing wave in quarter-wavelength straight-tube resonator.