Application of Smart Structures in Control Vibration and Energy Harvesting Technology

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1. Introduction

Piezoelectric materials as the most widely used materials in smart structures, provide many advantages to Vibration Control and Energy Harvesting (EH) applications. These materials have proven to be very effective in harvesting energy for low power devices such as implantable electronic devices and condition monitoring systems. Energy harvesting from environmental vibrations has also seen an increase in interest during the past years as part of the generally growing awareness for alternative energy sources.

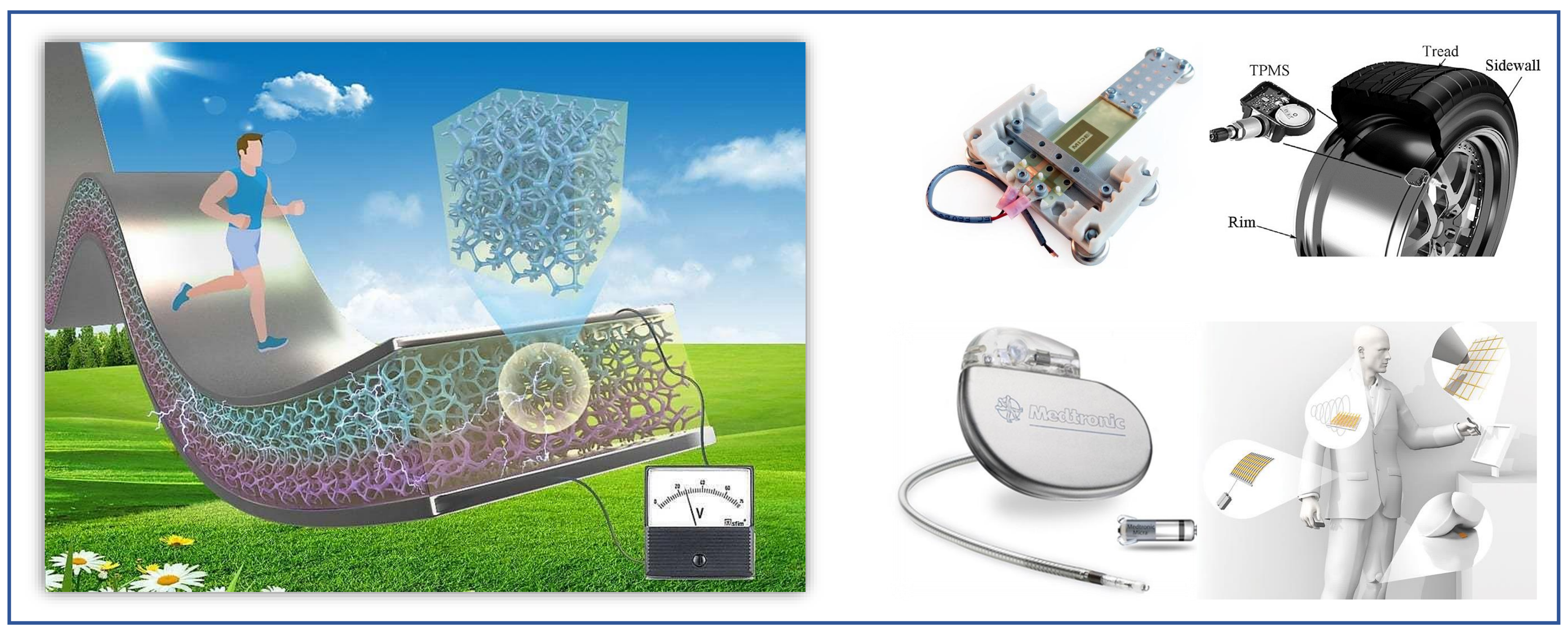
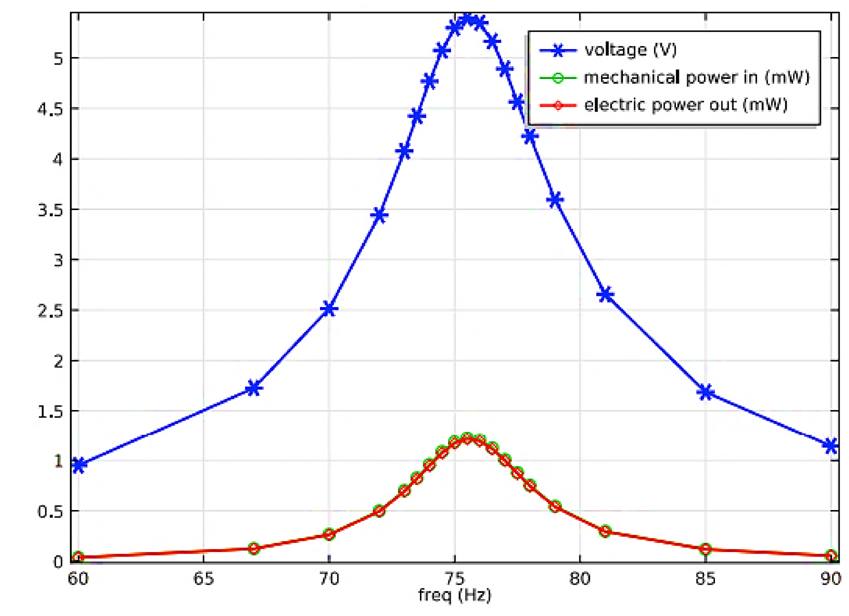


Fig. 1: Piezoelectric energy harvesting technology and its applications

Vibration-based piezoelectric energy harvesters (VPEHs) can produce peak power when their resonance frequency matches the frequency of the input ambient vibration (see Fig. 2). Any difference between these two frequencies can lead to a significant decrease in produced power.

Fig. 2: Power output as a function of vibration frequency [Comsol]



2. Motivation

One of the serious drawbacks of the existing designs of VPEHs is their high resonance frequencies compared to the frequencies of typical ambient vibrations. Thus, an eigen-frequency analysis could be useful to study the vibration behaviour of smart structures designed for EH applications. To this end, as the first part of this research, some **Analytical Solutions** have been developed to calculate the frequencies of various bimorph structures, and to investigate the effect of materials and geometry parameters on the system response.

3. Methodology & Results:

3.1. Bimorph Shells

A doubly curved shell made of porous core sandwiched between short- and open-circuit piezoelectric layers is considered as the bimorph structure. Using Hamilton's principle and the Maxwell equation, the governing equations of motion are derived based on first order shell theory. Finally, enforcing the mechanical boundary conditions results in the corresponding eigenvalue problem revealing the resonance frequencies.

$$N_{xx,x} + N_{xy,y} + Q_{xz}/R_x = I_0\ddot{u} + I_1\ddot{\psi}_x$$
$$N_{xy,x} + N_{yy,y} + Q_{yz}/R_y = I_0\ddot{v} + I_1\ddot{\psi}_y$$
$$M_{xx,x} + M_{xy,y} - Q_{xz} = I_1\ddot{u} + I_2\ddot{\psi}_x$$
$$M_{xy,x} + M_{yy,y} - Q_{yz} = I_1\ddot{v} + I_2\ddot{\psi}_y$$
$$Q_{xz,x} + Q_{yz,y} - (N_{xx}/R_x + N_{yy}/R_y) = I_0\ddot{w}$$
$$\text{Max. Eq: } \int_{-h-h_p}^{-h} \vec{\nabla}.\vec{D}\,dz + \int_{h}^{h+h_p} \vec{\nabla}.\vec{D}\,dz = 0$$

Applying the Analytical Solution

$$\{[K] - \omega^2[M]\}\{\Delta\} = 0$$

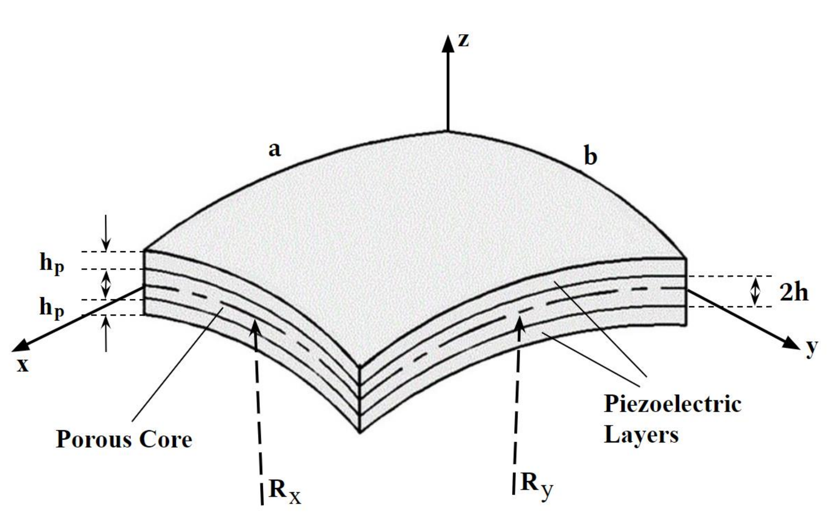
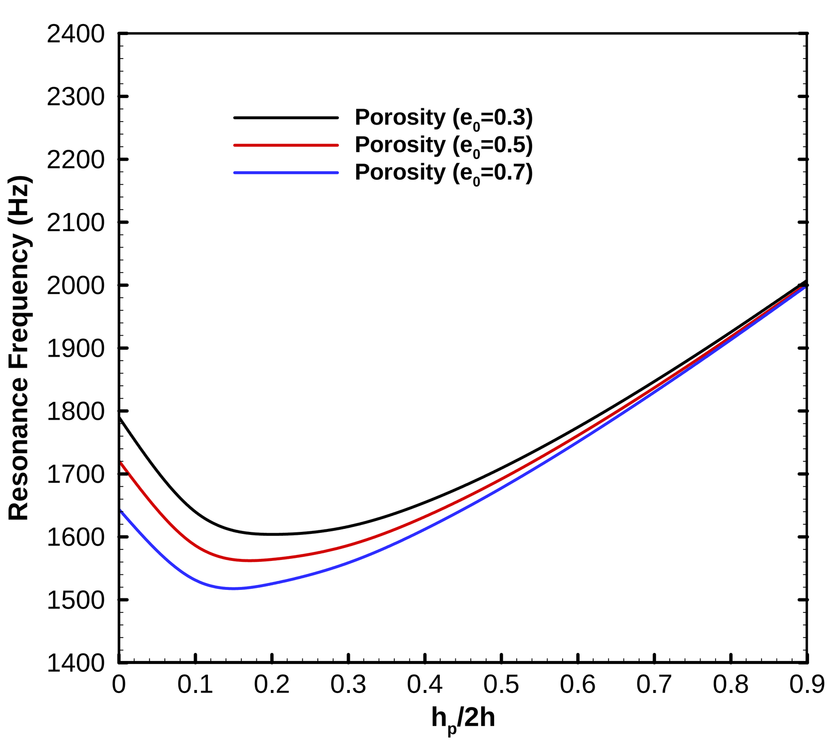
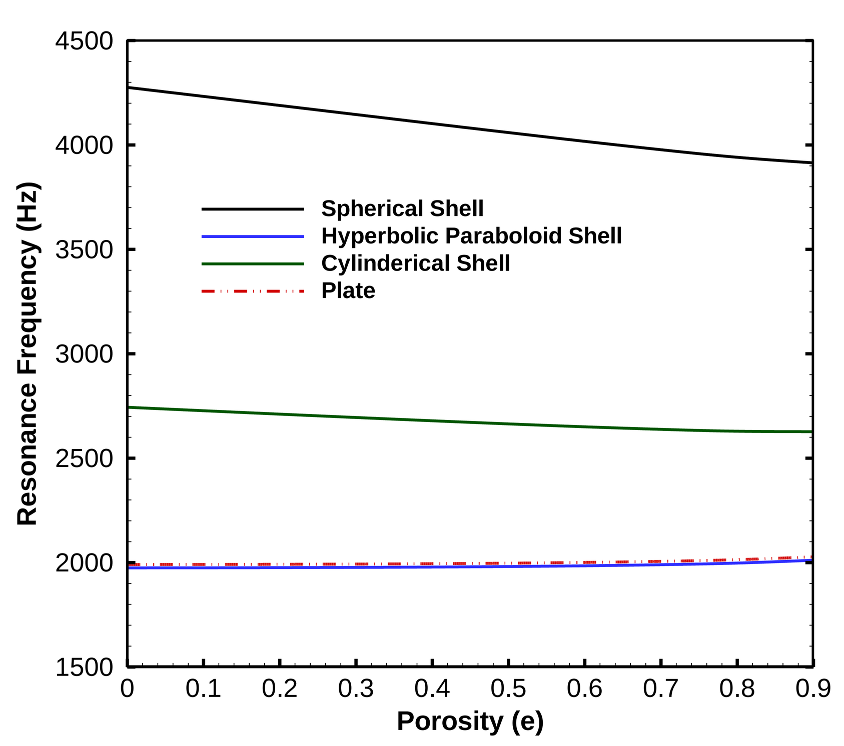
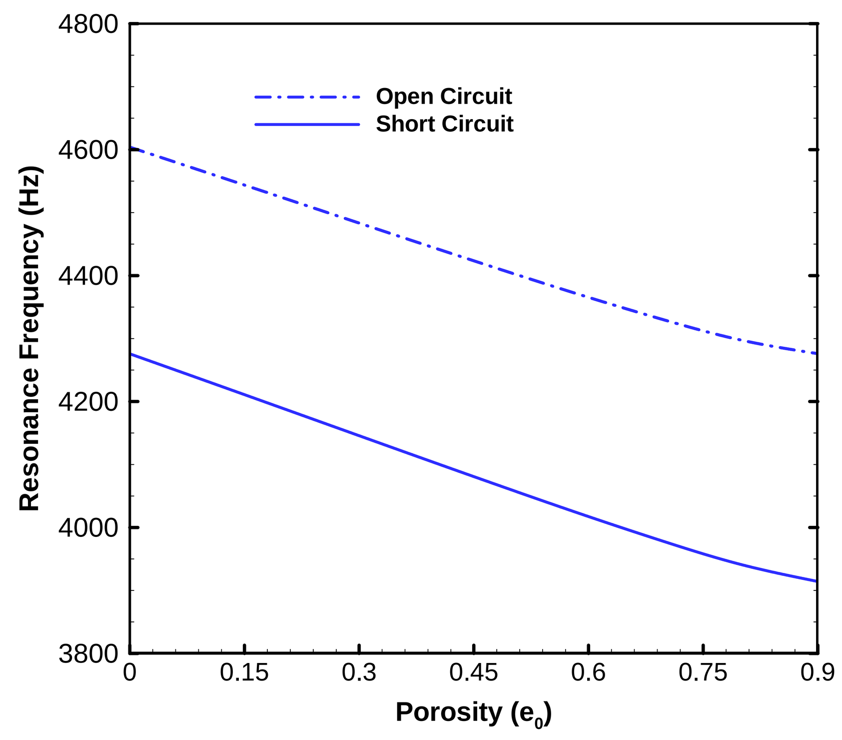
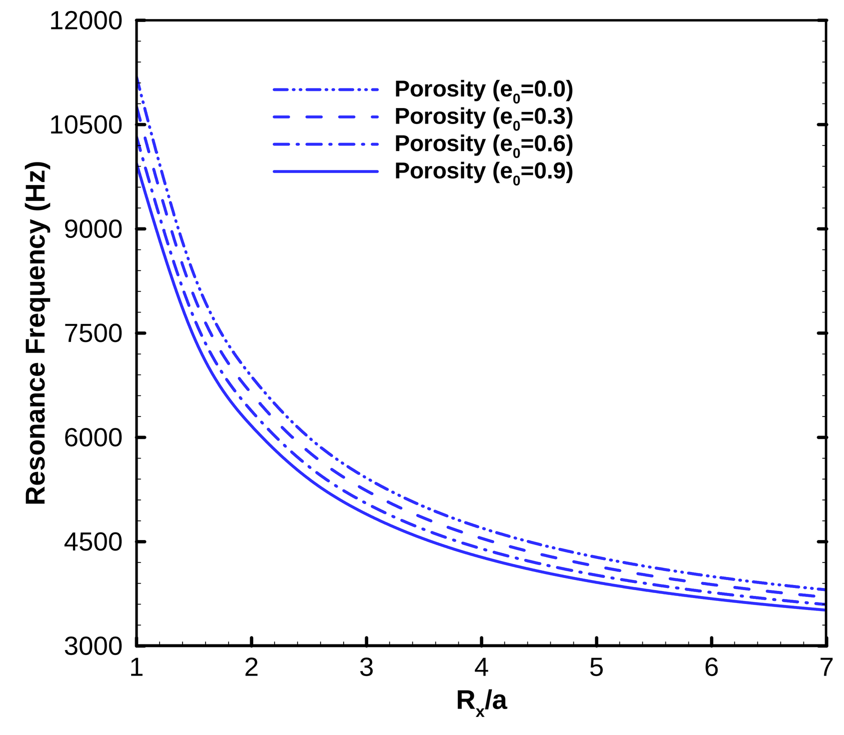


Fig. 3: Porous bimorph doubly curved shell



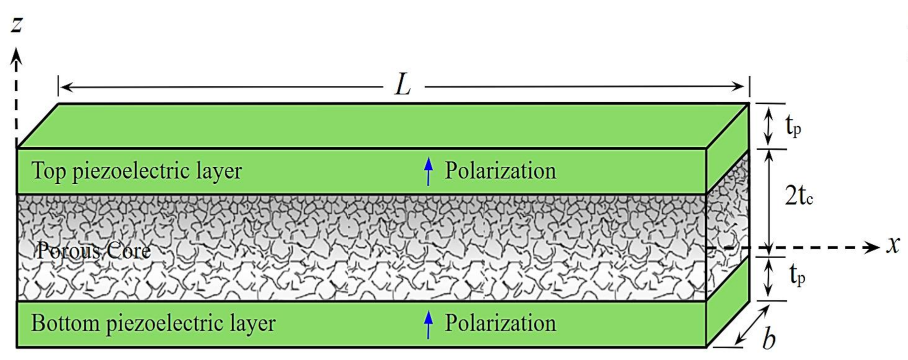






3.1. Bimorph Beams

In this section, the effects of transverse (d_{31}) and shear (d_{15}) piezoelectricity modes on the resonant frequencies of beam-like porous bimorph structures are investigated. Higher order beam theories are used to consider the effect of transverse shear deformation on the system response. Applying the same procedure (used in the previous section), the governing equations are derived and solved analytically, and the exact natural frequencies are finally calculated.



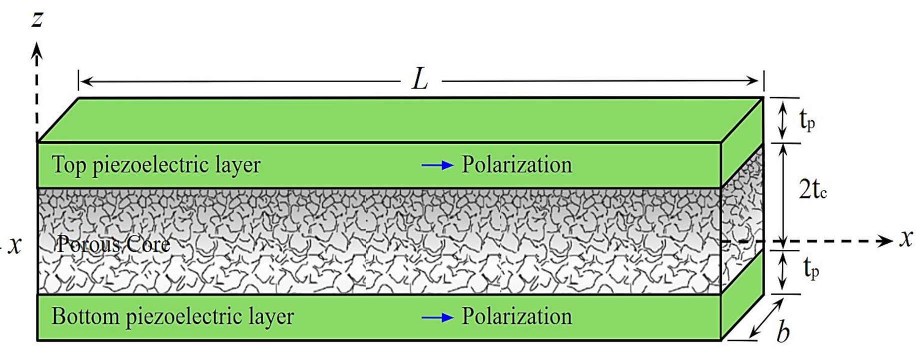
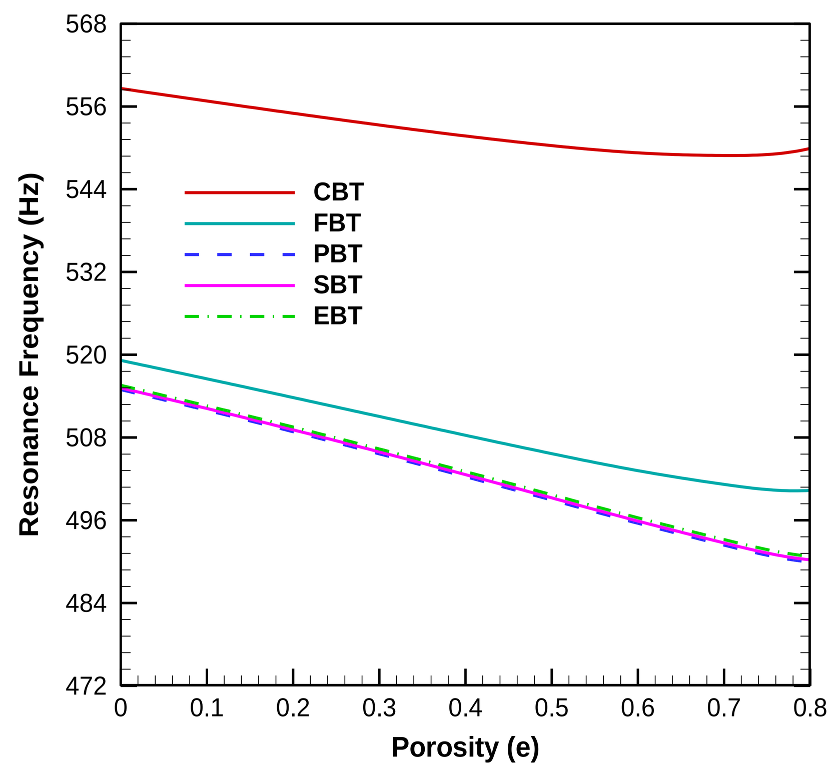
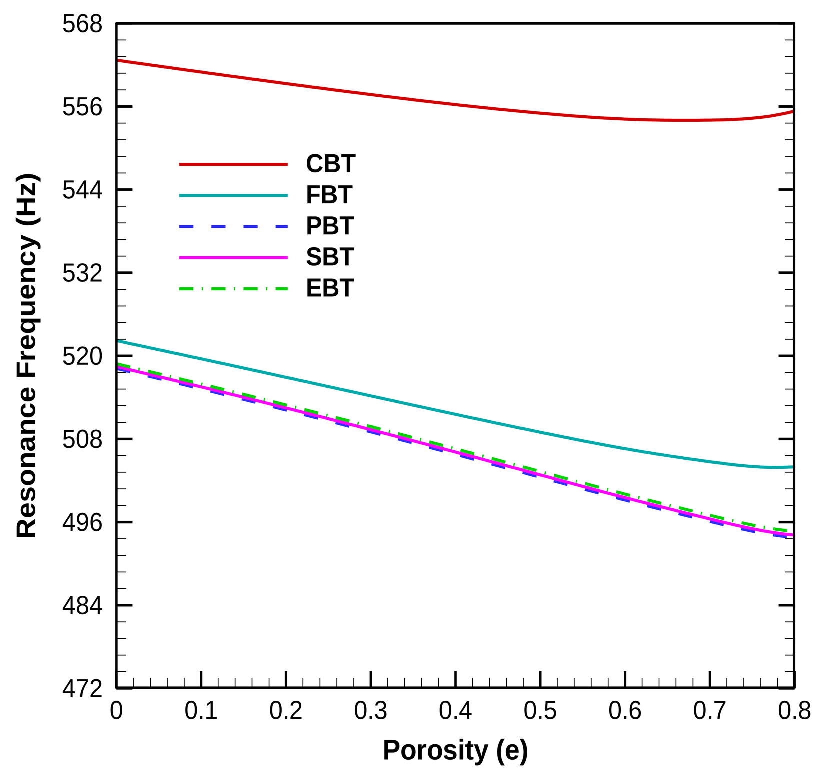
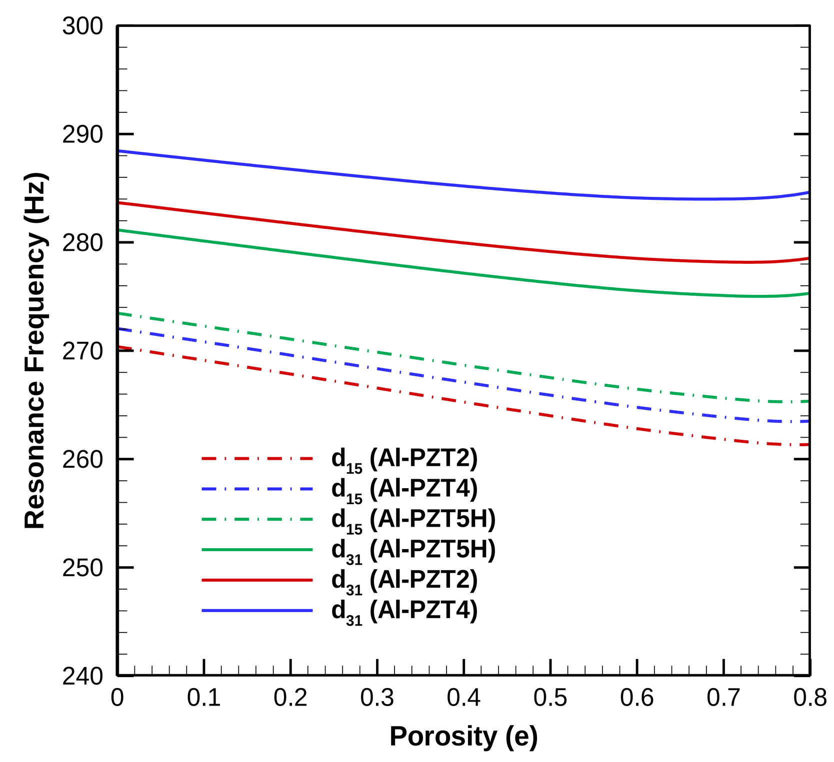
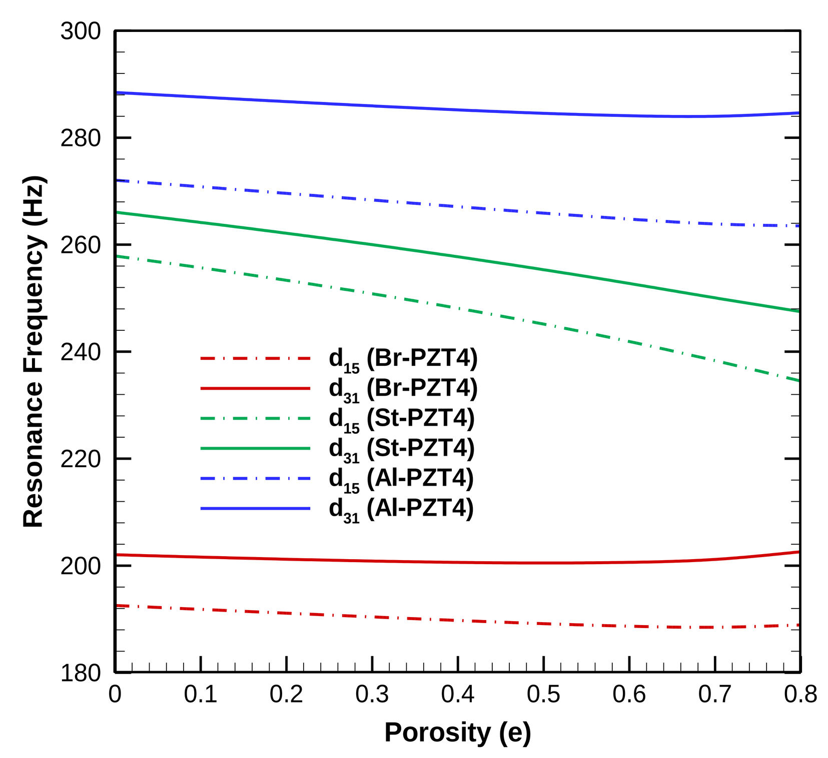


Fig. 4: Porous bimorph beam operated in transverse (left layout) and shear (right layout) modes of piezoelectricity









4. Conclusion

I. Increasing the spherical shell curvature significantly decrease its resonant frequencies.
II. For spherical, hyperbolic paraboloid shells and beam-like structures, increasing the porosity parameter (e) reduces the frequencies while a reverse trend is seen for cylindrical shells and plate bimorphs.
III. Bimorph beams with axial-poled piezoelectric layers result in lower resonant frequencies compared to the other piezoelectricity mode.
IV. The open-circuit resonance frequencies are larger than those of the short-circuit one.

5. Publication

I. M. Askari, E. Brusa and C. Delprete, "*Vibration Analysis of Porous Bimorph Doubly Curved Shells for Energy Harvesting Applications*", *8th International Conference on Mechanics and Materials in Design (M2D2019)*, 4-6 Sep 2019, Bologna, Italy.

II. M. Askari, E. Brusa and C. Delprete, "*Dynamic Analysis of Porous Bimorph Structures with Piezoelectric Layers Operated in Transverse and Shear Vibration Modes*", (Submitted).

6. Future Work

- Proposing novel piezoelectric EH devices for low power autonomous systems
- Development of piezoelectric composite materials for EH applications
- Experimental validation