ABSTRACT

In recent years, there is an increasing interest in the modeling and analysis of piezoelectric based energy harvesting system. Research and applications have been going on intensively, for more than two decades to improve the efficiency of piezoelectric energy harvesters. In this Thesis, exact solutions for the electromechnaical analysis of laminated piezoelectric bimorph energy harvester composed of laminated composite beam, plate and doubly curved **(DC)** shell substrates have been carried out. The layerwise exact solution for the static analysis of piezoelectric bimorph is derived using the governing equations, the constitutive relations showing the electromechanical coupling, the strain-displacement relationship and the electric field-potential relations. First the layerwise exact solutions for the mechanical displacements and electrical potential are derived. These expressions are then used to obtain the stresses and the electric displacements in terms of unknown constants which are solved satisfying prescribed boundary conditions.

First, the exact solutions for the simply supported piezoelectric bimorph laminated composite beam energy harvester whose piezoelectric layers are made up with **PZT5H** and the substrate beam layers are composed of continuous fiber reinforced composite material whose top piezoelectric layer is subjected to sinusoidally distributed upward mechanical load have been derived. The finite element analysis is also carried out to investigate the harvesting capability of the piezoelectric bimorph laminated beam energy harvester under general loading and boundary conditions. The results of the finite element method are in good agreement with those of the exact solutions. Both series and parallel connections of the piezoelectric layers have been considered to investigate the capability of the energy harvesters. The investigation reveals that the piezoelectric bimorph connected in series is capable of harvesting more energy from the deformed laminated composite beam than the bimorph connected in parallel. The exact static analysis and finite element solutions revealed that the piezoelectric bimorph energy harvesters whose substrate layers are composed of antisymmetric angle ply laminated beam have better capability of harvesting. Further, by augmenting the exact solutions and the finite element model derived for the bimorph the exact solutions and the finite element model of the unimorph piezoelectric energy harvester composed of laminated composite beam substrate and a piezoelectric layer attached on the top surface of the substrate has been derived. It has been explored by the investigations carried out here that for the same mass and

volume of piezoelectric layers the bimorph have significantly better harvesting ability than the unimorph.

Further, the exact solutions and the finite element model for the static analysis of the rectangular piezoelectric bimorph energy harvester composed of laminated composite plate substrate and orthotropic/generally orthotropic piezoelectric layers are derived in this thesis. The mostly used poled piezoceramics such as **PZT5H** are transversely isotropic. It has been importantly explored that the exact solutions for the piezoelectric energy harvesters composed of composite plate substrates and **PZT5H** as the piezoelectric material cannot be derived. Hence, the piezoelectric layers of the plate type energy harvesters have been considered to be made of the three dimensional orthotropic **PVDF** and the substrate plate layers are composed of continuous fiber-reinforced composite material. All linear theories of elasticity and piezoelectricity have been exactly solved to obtain the solutions of the harvesters while satisfying the associated edge boundary conditions, interface continuity conditions, prescribed boundary conditions and electrical boundary conditions. The main novelty of this research is that the exact solutions for the static analysis of antisymmetric angle ply laminated bimorph plate energy harvester have been derived. Using these exact solutions, the optimum values of the off-axis angle in the generally orthotropic piezoelectric layer, the length over width ratio of the harvester and the thickness of the piezoelectric layers for achieving maximum induced electric potential can be determined in a straightforward manner. The exact solutions derived here may serve as the benchmark solutions for verifying the experimental and numerical investigations.

Finally, the exact solutions and the finite element model for the **DC** shell type piezoelectric bimorph energy harvesters composed of laminated cross-ply as well as antisymmetric angle-ply laminated **DC** substrates and orthotropic/generally orthotropic piezoelectric layers have been derived in this thesis. **DC** shell substrates considered here are spherical, paraboloid and hyperboloid. It is explored that the harvesting capability of the hyperboloid DC Shell bimorph harvester is maximum when compared with spherical and paraboloid DC Shell bimorph harvesters.