Static and Harmonic Behaviour of Piezoelectric Beam Bending Actuators

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Abstract
This paper presents a general partial differential equation toolbox 3D under environment Matlab able to analysis of 3D FEM time harmonic problems in piezoelectric materials. The governing equations of these phenomena are solved simultaneously using a strong coupling model based on the finite element method, the model applied to a piezoelectric beam bending actuator and the results are compared with Comsol Multiphysics results and theory result.

Keywords: piezoelectric, strong coupling, Frequency domain

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1. Introduction

Piezoelectric materials become electrically polarized when strained. From a microscopic perspective, the displacement of atoms within the unit cell (when the solid is deformed) results in electric dipoles within the medium. In certain crystal structures this combines to give an average macroscopic dipole moment or electric polarization. This effect, known as the direct piezoelectric effect, is always accompanied by the converse piezoelectric effect, in which the solid becomes strained when placed in an electric field.

The use of piezoelectric materials as smart structures like actuators and sensors for noise and vibration control has been demonstrated extensively over the past few years [1-2]. The advantages offered by these materials are low weight, high stiffness, high frequency response, being easily controllable by the application of voltage, high actuation performance…etc.

There are two classes of piezoelectric materials used in vibration control: ceramics and polymers. The best known piezoceramic is the Lead Zirconate Titanate (PZT); it has a recoverable strain of 0.1% and is widely used as actuator and sensor for a wide range of frequencies, including ultrasonic applications; it is well suited for high precision as well. Piezopolymers are mainly used as sensors; the best known is the Polyvinylidene Fluoride (PVDF). The PVDF were first studied by Kawai (end of the 60's) and were made commercially available in the early 80's [3].

Several theories and analytical models [4-6] have been proposed in the process of investigations on the static and dynamic behaviour and actuation performance of the piezoelectric smart structures. Finite Element Method (FEM) based numerical studies [7-10] contributed to the field of piezoelectric smart structures significantly. It is very adapted for formulation of elements for modelling, static analysis, dynamic analysis and vibration control studies.

The beam bending has a very simple geometry that can be implemented in the modelling software and presents extensive applications in civil engineering. Its finite element modelling as actuator has received a considerable interest in recent years.in 1946 Cady has published work on the introduction to the theory and applications of electromechanical phenomena in Crystals [11]. After that in 1990, Crawley and Anderson have detailed models of piezoceramic actuation of beams [12]. More recent, a new shear actuated smart structure beam element is proposed by Benjeddou and al. In 1999 [13]. In 2001 Piefort and Preumont have proposed a finite element modelling of piezoelectric active structures [14]. In the field of Macro-electro-mechanical systems (MEMS), Srinivara and al. In 2012 have proposed a design and simulation of MEMS based piezoelectric shear actuated beam [15].

The study of piezoelectric phenomena is usually done with commercial software like COMSOL-Multiphysics, ANSYS and other. All these softwares present the studied problem as a black box and introducing of any modification is not possible. For this reason, we have developed in this work new Toolbox under MATLAB software. The developed Toolbox is called "FEM3DPIE", which is very flexible and permits us to study all the piezoelectric phenomena in 3D and can predict accurately deformation of actuator in both static and harmonic studies.

2. PDE for piezoelectric solid

The elastic behaviour of the solid is described by the equilibrium equation: