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Elastic Waves in Generalized Thermo-Piezoelectric Transversely Isotropic Circular Bar Immersed in Fluid

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Abstract. In this paper, a mathematical model is developed to study the wave propagation in an infinite, homogeneous, transversely isotropic thermo-piezoelectric solid bar of circular cross-sections immersed in inviscid fluid. The present study is based on the use of the three-dimensional theory of elasticity. Three displacement potential functions are introduced to uncouple the equations of motion and the heat and electric conductions. The frequency equations are obtained for longitudinal and flexural modes of vibration and are studied based on Lord-Shulman, Green-Lindsay and Classical theory theories of thermo elasticity. The frequency equations of the coupled system consisting of cylinder and fluid are developed under the assumption of perfect-slip boundary conditions at the fluid-solid interfaces, which are obtained for longitudinal and flexural modes of vibration and are studied numerically for PZT-4 material bar immersed in fluid. The computed non-dimensional frequencies are compared with Lord-Shulman, Green-Lindsay and Classical theory theories of thermo elasticity for longitudinal and flexural modes of vibrations. The dispersion curves are drawn for longitudinal and flexural modes of vibrations. Moreover, the dispersion of specific loss and damping factors are also analyzed for longitudinal and flexural modes of vibrations.

AMS subject classifications: 43.40.Ey, 43.88.Fx, 43.40.Cw, 43.20.Bi

Key words: Piezoelectric cylinders/plates, thermo-elastic, thermal cylinder immersed in fluid, solid- fluid interaction, transversely isotropic cylinder.

1 Introduction

The piezoelectric materials have been used in numerous fields taking advantage of the flexible characteristics of these polymers. Some of the applications of these polymers include Audio device-microphones, high frequency speakers, tone generators and acoustic modems; Pressure switches–position switches, accelerometers, impact detectors, flow

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meters and load cells; Actuators-electronic fans and high shutters. Since piezoelectric polymers allow their use in a multitude of compositions and geometrical shapes for a large variety of applications from transducers in acoustics, ultrasonic's and hydrophone applications to resonators in band pass filters, power supplies, delay lines, medical scans and some industrial non-destructive testing instruments.

The piezoelectricity was discovered by the brothers Curie in 1880 (Curie and Curie, 1880). The piezoelectric materials generally are physically strong and chemically inert, and they are relatively inexpensive to manufacture. The composition, shape and dimension of piezoelectric ceramic elements can be tailored to meet the requirements of a specific purpose. Ceramics manufactured from formulations of lead zirconate/ lead titanate exhibit greater sensitivity and higher operating temperatures, relative to ceramics of other compositions and the materials PZT-4 are most widely used piezoelectric ceramics.

The coupling between the thermal/electric/elastic fields in piezo electric materials provides a mechanism for sensing thermo mechanical disturbances from measurements of induced electric potentials, and for altering structural responses via applied electric fields. One of the applications of the piezo thermoelastic material is to detect the responses of a structure by measuring the electric charge, sensing or to reduce excessive responses by applying additional electric forces or thermal forces actuating. If sensing and actuating can be integrated smartly, a so-called intelligent structure can be designed. The piezoelectric materials are also often used as resonators whose frequencies need to be precisely controlled. The coupling between the thermoelastic and pyroelectric effects, it is important to qualify the effect of heat dissipation on the propagation of wave at low and high frequencies.

The thermo- piezoelectric theory was first proposed by Mindlin [1], later he derived the governing equations of a thermo-piezoelectric plate [2]. The physical laws for the thermo-piezoelectric materials have been discussed by [3, 4]. Chandrasekhariah [5, 6] presented the generalized theory of thermo-piezoelectricity by taking into account the finite speed of propagation of thermal disturbance. Yang and Batra [7] studied the effect of heat conduction on shift in the frequencies of a freely vibrating linear piezoelectric body with the help of perturbation methods. Sharma and Pal [8] discussed the propagation of Lamb waves in a transversely isotropic piezothermoelastic plate. Sharma et al. [9] investigated the free vibration analysis of a homogeneous, transversely isotropic, piezothermoelastic cylindrical panel based on three dimensional piezoelectric thermoelasticity. Sharma and Walia [10] presented the propagation of straight and circular crested waves in generalized piezo thermoelastic materials.

Tang and Xu [11] derived the general dynamic equations, which include mechanical, thermal and electric effects, based on the anisotropic composite laminated plate theory. They also obtained analytical dynamical solutions for the case of general force acting on a simply supported piezo thermoelastic laminated plate and harmonic responses to temperature variation and electric field have been examined as a special case. Tauchert [13] applied thermo-piezoelectricity theory to composite plate. The generalized theory of thermoelasticity was developed by Lord and Shulman [13] involving one relaxation time