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Surface electro-elastic Love waves in a layered structure with a piezoelectric substrate and a dielectric layer

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Abstract

The existence and behaviour of electro-elastic surface Love waves in a structure consisting of a piezoelectric substrate of crystal classe 6, 4, 6 mm, 4 mm, 622 or 422, an elastic layer and a dielectric medium is considered. The mathematical model obtained includes all the above crystal classes, i.e. the surface wave problems related to all these classes are presented in a single mathematical model. The dispersion equation for the existence of Love surface waves with respect to phase velocity is obtained. A detailed investigation of the electromechanical coupling coefficient is carried out depending on the dielectric and piezoelectric parameters of the problem. Geometrical investigation of the solutions of the dispersion equation is carried out.

Keywords: Love wave; Layered piezoelectric structure; Phase velocity; Electromechanical coupling coefficient

1. Introduction

Surface acoustic wave devices have been widely used in signal transmission, signal processing and information storage applications since the 1970s (Morgan, 1998). The high performance of these devices is related to the electromechanical coupling coefficient, the efficiency of the energy transducer and their working reliability and stability. Transmitting and receiving devices are mainly made from piezoelectric materials due to the ease of manufacturing and utilisation and their high sensitivity. To achieve high performance many such devices/sensors adopt layered piezoelectric structures consisting of a piezoelectric layer and an elastic substrate or an elastic layer and a piezoelectric substrate.

One type of surface acoustic wave is the Bleustein–Gulyaev wave which exists only in piezoelectric materials (Bleustein, 1968; Gulyaev, 1969) and may have certain advantages in some devices because of its simpler particle motion. Many papers are published on the propagation of Bleustein–Gulyaev waves in piezoelectric layered structures. Identical piezoelectric layer/substrate structure with opposite polarization with or without initial stresses is considered in Jin et al. (2001, 2002) and Liu et al. (2003).

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The Love surface wave is another type of surface acoustic wave which exists only when there is a surface layer of finite thickness overlying a substrate of a different material and when the bulk shear wave velocity in the layer is less than that in the substrate. Love wave devices combine very high sensitivities with the possibility of sensing in liquids. The application of Love waves in an electronic sensor system is discussed in Jakoby and Mibhae (1997). Conditions for the existence of Love surface waves are developed in a piezoelectric material of class 6 mm carrying a metal layer of finite thickness in Curtis and Redwood (1973). Many papers are devoted to the investigation of propagation behaviour of Love waves in piezoelectric layer/substrate structure with or without initial stresses (Liu et al., 2001; Wang et al., 2001; Jin et al., 2005; Qian et al., 2004). A prestressed elastic layer/piezoelectric substrate system has been studied in Jin et al. (2000).

With piezoelectric media involved, the calculation of the dispersion relation becomes more complicated. The layered structures considered so far consisted mainly of crystal classes 6 mm and 4 mm. The mathematical model of the problem in this case contains only one piezoelectric constant. However new and interesting phenomena may occur when piezoelectric properties of the substrate are more complicated, i.e. there are two or more piezoelectric constants in the mathematical model. The objective of this paper is to discuss the existence and behaviour of electro-elastic surface Love waves in a structure consisting of a piezoelectric substrate of crystal classe 6, 4, 6 mm, 4 mm, 622 or 422, an elastic layer, and an adjoining dielectric medium on the top which has no acoustic contact with the layer. The top dielectric medium is to regulate the wave process in the layered structure. First the dispersion equation is obtained and the electromechanical coupling coefficient is investigated in detail. The behaviour of the solutions of the dispersion equation is studied depending on the piezoelectric and dielectric parameters of the layered structure.

2. The statement of the problem

We consider a dielectric isotropic layer of thickness h rigidly linked to the piezoelectric half-space substrate either of classe 6, 4, 6 mm, 4 mm, 622, 422 (Fig. 1). Examples of piezoelectric materials of crystal classes 6, 4, 6 mm, 4 mm, 622, 422 include respectively lithium iodate LiO_3, potassium strontium niobate $KSr_2Nb_5O_{15}$, cadmium sulphide CdS, barium titanate $BaTiO_3$, β-quartz SiO_2, and paratellurite TeO_2. The dielectric layer can be any isotropic material, or any anisotropic material with the same anisotropy as the substrate. The coordinate system $Ox_1x_2x_3$ is chosen in such way that the Ox_3 axis is directed along the main direction of the piezoelectric substrate (L_4 or L_6), the plane $x_1 = 0$ occupies the boundary between the layer and the substrate, and the Ox_1 axis points down into the substrate.

The domain $x_1 < -h$ is assumed to be either a vacuum or it is occupied by a dielectric medium without an acoustic contact with the layer. The layer surfaces $x_1 = 0$ and $x_1 = -h$ are electrically open and the surface $x_1 = -h$ is free of external forces (mechanically free).

It is well known that elastic and electric excitations in a piezoelectric media are interconnected and are described in a quasi-static approximation by the following equations:

$$\frac{\partial \sigma_{ik}}{\partial x_k} = \rho \frac{\partial^2 u_i}{\partial t^2}, \quad \text{(equations of motion)} \tag{2.1}$$

$$\vec{E} = -\text{grad}\,\varphi, \quad \text{div}\,\vec{D} = 0, \quad \text{(Maxwell's equations)} \tag{2.2}$$

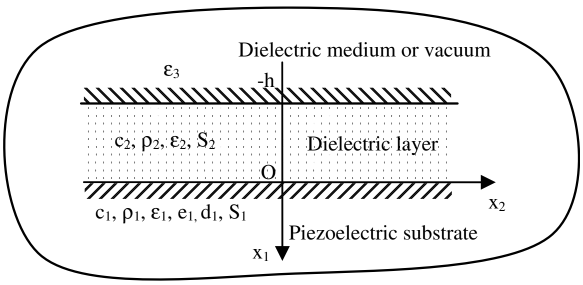

Fig. 1. The layered half-space for dielectric layer and piezoelectric substrate.