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Interface waves on the sliding contact between identical piezoelectric crystals of general anisotropy

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Abstract

The theory is developed of acoustic waves guided by the perfect sliding contact between identical piezoelectric crystals. The wave propagation under two types of electric boundary conditions has been investigated: (1) non-metallized interface; (2) metallized interface. The main attention has been paid to the so-called subsonic slip waves. A number of theorems has been proved concerning the existence of such waves in structures of arbitrary symmetry. A thorough study of the existence conditions for slip waves has been carried out as applied to structures assuming certain particular orientations. The results of analytic considerations have been illustrated by numerical computations.

Keywords: Acoustic waves; Sliding contact; Piezoelectric crystals

1. Introduction

The plane wave propagation in bounded anisotropic solids can be studied analytically by solving the relevant wave equations and boundary equations only for a restricted amount of geometries of propagation connected with the elements of crystallographic symmetry. The reason is that the decay factor, or normal component of the wave vector, of partial modes generally obeys an algebraic equation of eighth or sixth degree depending on whether the crystal is piezoelectric or not, e.g. [1–3]. This equation becomes split into equations of lower degree in the case of isotropic solids and for particular orientations of crystals. Note that of the acoustoelectric wave problems only the shear horizontally polarized modes can be investigated explicitly[1] (see Refs. [4–9]).

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[1] In principle, one can derive the dispersion equation for surface waves on half-infinite substrates in the form of an algebraic equation avoiding the calculation of the decay factors [10]. But the equations obtained are of 27th and more than of 100th degree with respect to the square of velocity for non-piezoelectric and piezoelectric crystals, respectively, and its solubility cannot be analyzed.

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Given an anisotropic structure and geometry of propagation, the permissible waves can be found numerically. On the other hand, the numerical methods fail to address some challenges of crystal acoustics, such as the existence conditions for waves guided by various interfaces or the connection amid the occurrence of waves of different types.

It is of interest that the existence problems are available for analytic studies in fact. They appear to be solvable without evaluating the plane waves parameters. It suffices to take advantage of a number of general relations these parameters obey. Such an approach has been successfully applied to surface and interface acoustic wave theory in non-piezoelectric and piezoelectric media [11–22]. The same method has allowed one to study the occurrence of quasi bulk waves on the corrugated surface of anisotropic substrates [23], to analyze properties of the frequency spectrum of acoustic waves propagating under metallic gratings [24] as well as the existence of leaky waves and high-velocity non-attenuating localized waves in homogeneous and layered structures [25–28].

The present paper is devoted to interface waves on the perfect sliding contact between piezoelectric crystals. It should be said that slip waves in structures formed of two different general anisotropic solids have earlier been considered in Refs. [20–22] and the maximum number of subsonic waves supported by such structures has been determined. By “subsonic” we mean an interface wave propagating slower than the slowest limiting bulk wave, i.e. slower than all bulk waves (see Fig. 1). It has been proved that at most two slip waves exist in structures without piezoeffect [20] and at most three waves exist in piezoelectric structures [22]. No slip subsonic waves exist if no surface waves exist on the mechanical free surfaces of the crystals that form the structure. In Ref. [20,21] the existence conditions for the second slip wave on the contact between identical non-piezoelectric crystals have been discussed in details.

“Sliding” structures, like other ones, also support leaky waves. Some specific features of the resonance reflection of plane waves and bounded acoustic beams in the vicinity of a leaky slip wave branch have been discussed in Ref. [29]. A thorough investigation of the reflection of plane waves incident in the plane of symmetry onto the sliding contact between orthotropic non-piezoelectric crystals has been performed in Ref. [30]. Note that the propagation of non-leaky purely localized slip waves in orthotropic media has been studied in Ref. [31].

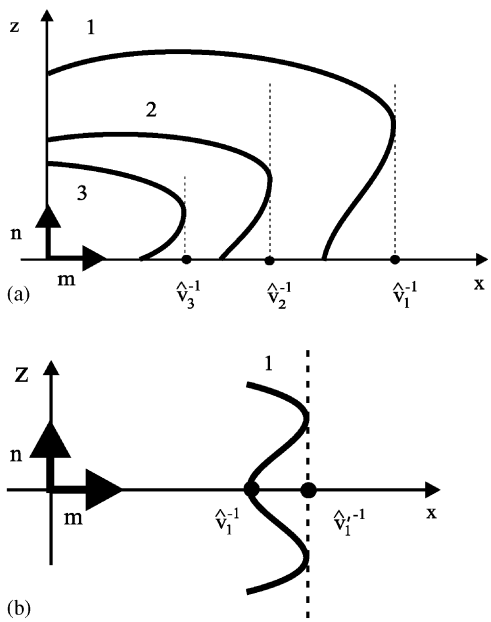

Fig. 1. Geometry of propagation and slowness curves of bulk waves—1: slow quasi transverse wave, 2: fast quasi transverse wave, 3: quasi longitudinal wave; $\hat{v}$ and $\hat{v}_{1,2,3}$: limiting velocities. Subsonic velocity interval: $v < \hat{v}_1$, 1st intersonic velocity interval: $\hat{v}_1 < v < \hat{v}_2$, 2nd intersonic velocity interval: $\hat{v}_1 < v < \hat{v}_2$. Transonic states of Type 1: $v = \hat{v}_{1,2,3}$ in (a) and $v = \hat{v}_1$ in (b). Transonic state of Type 4: $v = \hat{v}'_1$ in (b).