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Subsonic slip waves along the interface between two piezoelectric solids in sliding contact with local separation

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Abstract

The Stroh formalism of piezoelectric crystals and singular integral equation technique are applied to study the propagation of possible slip waves in presence of local separation at the interface between two frictionless contact piezoelectric solids, which are pressed together by uniaxial pressure and laid in the electric field. The problem is cast into a set of singular integral equations of which the closed solutions are obtained. Discussion on the existence of such slip waves is presented. The results show that such slip waves, which have square-root singularities at both ends of the local separation zones, can propagate in some special material combinations. And the existence of such slip waves is related with the applied mechanical and electric fields.

Keywords: Piezoelectricity; Interface; Slip wave; Stroh formalism; Singular integral equations

1. Introduction

Plane waves propagating along the surface or interface of a solid, attenuating exponentially with distance from the surface or interface, are called "surface waves" or "interface waves", such as the well known Rayleigh and Stoneley waves which play important roles in geophysics, seismology, earthquake engineering and non-destructive evaluation, etc. Since the 1970s, the theories of existence and uniqueness of Rayleigh and Stoneley waves in anisotropic solids had been completely established through the efforts of Barnett and Lothe [1–4], and Chadwick and Smith [5]. Their analysis is based on the Stroh formalism and makes use of the "surface impedance tensor" which is proved to be a powerful tool in analyzing wave problems in anisotropic solids [6]. Extending the Stroh formalism from anisotropic elastic solids to piezoelectric crystals, Lothe and Barnett [7,8] discussed which kind of boundary condition would admit the existence of surface waves. Later, Abbudi and Barnett [9] studied the Stoneley waves propagating along the interface between two generally piezoelectric solids.

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The interface wave theory is generally based on the assumption of the welded interface, i.e. the tractions and displacements are continuous across the interface. However, contact interfaces, smooth or frictional, are also common in practical cases, e.g. crack surfaces, bolted or press-fit connections in mechanical systems, pre-existing faults in the earth crust, etc. Unlike welded interfaces, the contact interfaces cannot support tensile force and may slip with or without friction. The possibility of interface waves between two isotropic elastic solids which are pressed together and can slip with respect to each other without friction was studied by Achenbach and Epstein [10]. This kind of waves, a variation of the Stoneley waves, was called "slip waves" by Barnett et al. [11] who discussed the existence of such slip waves in general anisotropic solids and pointed out that the second slip waves may propagate due to the elastic anisotropy. Later, further discussion on such slip waves was presented by Wang and Lothe [12]. The recent studies on slip waves in piezoelectric media can be found in the articles by Alshits [13] and Darinskii [14].

One may found that all of the above-mentioned publications assumed that the slip waves did not cause the disturbance involving local separation along the interface. However, local separation may take place if the waves are strong enough or the applied pressure is relatively lower. In 2003, Wang et al. [15] investigated the slip waves propagating along a smooth interface between two anisotropic solids in sliding contact with local separation. Recently, they analyzed a more complex problem—the slip waves and steady sliding at the interface between two anisotropic elastic half-spaces in frictional contact with stick-slip [16]. In this paper, we will devote to theoretical study on the existence of the interfacial slip waves which can cause the local separation distributing periodically along the interface between two dissimilar piezoelectric half-spaces. The Stroh formalism for piezoelectric media and the conception of "surface impedance tensor", together with the singular integral equations technique, will be used. This topic is relevant to non-destructive evaluation of the interfacial debonding in layered piezoelectric structures which are widely used in transducers, and to mechanism of motion transformation in ultrasonic motors [17], etc. In addition, piezoelectric media are generally anisotropic. Anisotropy together with piezoelectric effects not only requires different mathematical methodology in solving the problem, but also may bring in some new aspects in physics. We expect the present analysis may bring up questions of general interest in slip dynamics and Rayleigh–Stoneley-wave theory involving contact interfaces in piezoelectric media.

2. Problem formulation

2.1. Stroh formalism and surface impedance tensor

Consider two homogeneous anisotropic linear elastic piezoelectric half-spaces $\langle 1\rangle$ and $\langle 2\rangle$ which are pressed together by remote pressure p_0 and in frictionless sliding contact along a planar interface, see Fig. 1. At the same time, the piezoelectric solids are loaded at the infinity with the uniform electric displacement D_0.

We study slip waves propagating in direction **m** along the interface with unit normal **n**. The general theoretical considerations are mainly based on the Stroh formalism for piezoelectric materials [13,14]. The basic equations of motion for generally anisotropic linear piezoelectric media are [18]

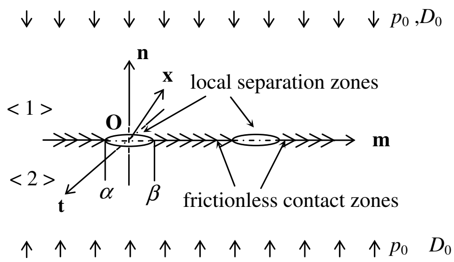

Fig. 1. Local separation and frictionless contact zones on the interface between two homogeneous anisotrpic linear elastical piezoelectric half-spaces.