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Short Communication

PECULIARITIES STUDY OF ACOUSTIC WAVES' PROPAGATION IN PIEZOELECTROMAGNETIC (COMPOSITE) MATERIALS

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ABSTRACT

This short paper has the purpose to discuss different coupling mechanisms that can be revealed in the coefficient of the magnetoelectromechanical coupling (CMEMC). Concerning the propagation problems of the shear-horizontal acoustic waves in the piezoelectromagnetics such as bulk homogeneous materials, inhomogeneous composites, and homogeneous plates, these CMEMC coupling mechanisms must be accounted to obtain wave characteristics in various configurations exploiting the smart piezoelectromagnetic materials. Indeed, many wave characteristics are already known for the shear-horizontal waves such as the surface, interfacial, and plate acoustic waves. It is obvious that they can have potential applications in the physical, biological, and chemical sensors, non-destructive testing and evaluation, etc.

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INTRODUCTION AND DISCUSSION

Piezoelectromagnetic (composite) materials, also frequently called the magnetoelectroelastic materials, are the well-known smart materials because the electrical subsystem of such materials can influence on the magnetic subsystem (and vice versa) via the mechanical subsystem. The interest in investigations of such smart materials is continuously growing that is seen in a large number of published review works. Using review paper (Zakharenko, 2013), the reader can find that already by about fifty reviews exist to this time. Today, piezoelectromagnetics can be utilized in various smart technical devices such as (biological and chemical) sensors, filters, delay lines, lab-on-a-chip, etc. Therefore, acoustic properties of such materials must be known.

The transversely isotropic (6 *mm*) piezoelectromagnetic materials are the most investigated and exploited because their characteristics can be disclosed in explicit analytical forms. This is extremely important for better understanding of their acoustic properties. However, even in the case of the employment of the quasi-static approximation (Auld, 1990; Dieulesaint and Royer, 1980) for the propagation of the shear-horizontal acoustic waves coupled with both the electrical and magnetic potentials, one can account a lot of material parameters of such smart materials. One of the very important characteristics of the smart materials is the coefficient of the magnetoelectromechanical coupling K_{em}^2 (CMEMC) that couples the material constants of the piezoelectromagnetics in the following formula:

$$K_{em}^2 = \frac{e(e\mu - h\alpha) - h(e\alpha - h\varepsilon)}{C(\varepsilon\mu - \alpha^2)} \quad (1)$$

Equality (1) contains the following independent nonzero material constants: the stiffness constant C, piezomagnetic coefficient h, piezoelectric constant e, dielectric permittivity coefficient ε, magnetic permeability coefficient μ, and electromagnetic constant α.

It is also clearly seen in equality (1) that the following coupling mechanisms containing the electromagnetic constant α can be apportioned in the CMEMC K_{em}^2:

$$e\mu - h\alpha \quad (2)$$

$$e\alpha - h\varepsilon \quad (3)$$

$$\varepsilon\mu - \alpha^2 \quad (4)$$

It is also indispensable to state that the values of $e(e\mu - h\alpha)$, $h(e\alpha - h\varepsilon)$, and $C(\varepsilon\mu - \alpha^2)$ in the CMEMC defined by expression (1) have the dimension of the mass density and can be therefore called the

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magnetoelectroelastic densities of coupling (MEEDC).

In dependence on the coupling mechanism which can play a major role, different wave characteristics of the propagation of the shear-horizontal acoustic waves in the piezoelectromagnetics can be obtained in explicit analytical forms. It is necessary to mention first theoretical works (Melkumyan, 2007; Liu *et al*., 2007; Wang *et al*., 2007; Wei *et al*., 2009) on the propagation of the shear-horizontal acoustic waves in such smart materials. In these recent works, the propagation of such acoustic waves along the boundary between the transversely isotropic (6*mm*) piezoelectromagnetic material and a vacuum was considered, i.e. the propagation of surface acoustic waves (SAWs) was treated. In these works, explicit analytical forms for the propagation of the piezoelectromagnetic SAWs localized at the boundary between two continuous media such as the piezoelectromagnetic half-space and a vacuum were obtained. Considering various mechanical, electrical, and magnetic boundary conditions at the boundary between the transversely isotropic piezoelectromagnetics and a vacuum, the author of theoretical work Melkumyan (2007) has demonstrated that twelve independent solutions can exist for the problem of the SAWs' propagation.

Following the results obtained in theoretical paper (Melkumyan, 2007), theoretical works Zakharenko (2010, 2011) have also studied peculiarities of the SAW propagation at the boundary between the piezoelectromagnetics and a vacuum exploiting different boundary conditions that are divided into mechanical, electrical, and magnetic ones. In book (Zakharenko, 2010), the SAW propagation in the transversely isotropic piezoelectromagnetics was also investigated and it was found that seven different SAWs can exist in addition to already discovered solutions (Melkumyan, 2007; Liu *et al*., 2007; Wang *et al*., 2007; Wei *et al*., 2009). The existence of these additional solutions discovered in Zakharenko (2010) is the consequence of the different coupling mechanisms (2), (3), and (4) clearly shown in the CMEMC (1). It is essential to state an analytical study of the propagation of the shear-horizontal SAWs in the transversely isotropic piezoelectromagnetic materials is significantly simpler in comparison with a study of the SAW propagation in the piezoelectromagnetics possessing the cubic symmetry. For the cubic piezoelectromagnetics, explicit analytical forms for the propagation velocities of the shear-horizontal SAWs cannot be revealed. As a result, the SAW velocities were calculated with numerical methods in Zakharenko (2011) that represents the single original work in this direction of the investigations.

It is worth mentioning theoretical works (Zakharenko, 2012 a,b) in which the shear-horizontal acoustic waves coupled with both the electrical and magnetic potentials propagating in the transversely isotropic piezoelectromagnetic materials were also studied. In a book Zakharenko (2012a), it was treated the propagation of such acoustic waves in non-homogeneous media consisting of two dissimilar piezoelectromagnetics with different mechanical, electrical, and magnetic properties and possessing the common interface, along which such non-dispersive acoustic waves can propagate. The propagation problems of dispersive shear-horizontal acoustic waves were considered in Zakharenko (2012b). This book studies the wave characteristics of the transversely isotropic piezoelectromagnetic plates representing the two-dimensional case. In this case, knowledge of the plate wave characteristics can allow the further miniaturization of various technical devices based on such smart (composite) materials. Also, the plate waves are widely used for non-destructive testing and evaluation of thin films. Concerning the applications in the aerospace industry, the plate waves can be used as one of the useful tools for inspecting of various defects of mechanical components with complex shapes.

CONCLUSION

These discussions introduced in this short paper can be useful for theoreticians and experimentalists working in the research arena of the propagation problems of the shear-horizontal acoustic waves in the smart piezoelectromagnetic materials such as the bulk homogeneous materials, inhomogeneous composites, and homogeneous plates. Indeed, one can account the coupling mechanisms discussed in this work in order to describe the propagation of the shear-horizontal acoustic waves in the piezoelectromagnetics. These acoustics waves can be useful, for instance, for applications in the non-destructive testing and evaluation.

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