Abstract

The propagation properties of surface acoustic waves (SAWs) in laminated structures have important applications for research in areas such as SAW devices, civil engineering, and geological exploration. For more complex layered structures, which generally need to be solved by numerical analysis, this paper combines the Rayleigh-Ritz method and the transfer matrix method to analyse the propagation characteristics of low-order SAWs in a two-dimensional finite elastic structure. Since the finite element method (FEM) is one of the most commonly used numerical calculation tools in the design and analysis of device structures, with its advantages of simplicity and ease of operation, this paper uses the Carrera Unified Formulation (CUF) framework combined with viscous-spring artificial boundaries to analyse the propagation properties of low-order SAWs in finite three-dimensional layered structures. The compact stiffness matrix form constructed using the CUF can effectively reduce the computational cost of finite elements while ensuring computational reliability. This paper presents a more systematic study of several fundamental wave problems in layered structures, to provide valuable theoretical references for the application and design of SAWs devices. Both methods can be used to characterise the propagation of SAWs in finite elastic plates covered with periodic electrodes, with the Rayleigh-Ritz method being more applicable to models with relatively simple structures, and finite element calculations can be performed using CUF for models with more complex cover shapes. The main contents and results of this paper are as follows:

(1) The propagation characteristics of SAWs in an isotropic elastic plate are investigated by the Rayleigh-Ritz method and by using a combination of the Legendre polynomial and a trigonometric form as a displacement function. The boundary conditions of the structure are taken into account in the trial function and the corresponding characteristic equations are obtained by substituting Lagrangian functions. The effects of boundary conditions and plate thickness on the dispersion characteristics, modes, and corresponding stress distributions of the low-order SAWs in the structure are investigated by numerical calculations. The study shows that the propagation characteristics of the low-order SAWs in the plate are related to the plate thickness; in the present model, the boundary condition on the bottom surface of the plate has little effect on the wave velocity of the low-order SAWs in the structure but has a certain degree of influence on the modes and the corresponding stress distributions.

(2) The effects of cover layer material, layer thickness, and each boundary condition on the dispersion characteristics of low-order SAWs in a finite elastic structure with a cover layer are discussed, taking into account the boundary conditions at the intersection. The results show that the cladding material has a significant effect on the wave velocities of the low-order SAWs in the structure; the cladding thickness within a certain range affects the wave velocities of the low-order SAWs in the structure; the stress boundary conditions at the intersection have a significant effect

on the modes and the corresponding stress distributions of the low-order SAWs.

(3) Combining the Rayleigh-Ritz method and the transfer matrix, the effects of the cover material, layer thickness, and each boundary condition on the dispersion characteristics of low-order SAWs in a finite elastic structure with a cover layer that does not completely cover the substrate layer are discussed. The results show that the free boundary conditions on both sides of the cover layer perpendicular to the wave propagation direction need to be considered in the calculation of this model, otherwise, numerical results consistent with the case where the cover layer is of equal width with the substrate layer are obtained; compared with the above-calculated model, the number of low-order SAW velocities in this calculated model varies in the same range of cover layer thicknesses.

(4) The effect of the number of electrodes and materials on the dispersion characteristics of low-order SAWs in a finite elastic plate covered with periodic electrodes with a fixed bottom edge of the substrate is discussed. The results show that the number of electrodes has almost no effect on the wave velocities of the low-order SAWs in the adopted model with the same structure, dimensions, and materials, but that different combinations of cover materials have a significant effect on the dispersion characteristics of the low-order SAWs in the structure.

(5) A compact stiffness matrix was constructed from the one-dimensional beam model of CUF and a viscous-spring artificial boundary was established at the model boundary to analyse the propagation characteristics of low-order SAWs in a finite three-dimensional layered structure. The results show that the size of the cover layer has a certain influence on the wave velocities of the low-order SAWs in the structure; in this computational model, the thickness of the cover layer has a relatively large influence on the wave velocities of the low-order SAWs in the structure, while the length of the cover layer has an extremely small influence on the wave velocities of the low-order SAWs in the structure.

Keywords: laminated structure, low-order SAWs, Rayleigh-Ritz method, the transfer matrix, CUF, viscous-spring artificial boundary