Identification of Vibration Modes of Quartz Crystal Plates with Proportion of Strain and Kinetic Energies

Qi Huang
Piezoelectric Device Laboratory, School of Mechanical Engineering and Mechanics, Ningbo University, 818 Fenhua Road, Ningbo, Zhejiang 315211, China.
Department of Architectural Engineering, Huzhou Vocational & Technical College, 299 Xuefu Road, Wuxing District, Huzhou, Zhejiang 313000, China.

Rongxing Wu
Department of Architectural Engineering, Ningbo Polytechnic, 1069 Xinda Road, Beilun District, Ningbo, Zhejiang 315800, China.

Lihong Wang, Longtao Xie, Jianke Du, Tingfeng Ma and Ji Wang†
Piezoelectric Device Laboratory, School of Mechanical Engineering and Mechanics, Ningbo University, 818 Fenhua Road, Ningbo, Zhejiang 315211, China.
† Corresponding author

(Received 5 November 2019; accepted 18 May 2020)

For the design of quartz crystal resonators, finding and determining the vibration modes have always been very important and cumbersome. Vibration modes are usually identified through plotting displacement patterns of each coupled modes and making comparisons. Over the years, there is not much improvement in the identification procedure while tremendous efforts have been made in refining the equations of the Mindlin plate theory to obtain more accurate results, such as the adoption of the Finite Element Method (FEM) by implementing the high-order Mindlin plate equations for efficient analysis. However, due to the old fashioned mode identification method, the FEM application is still inadequate and cannot be fully automated for this purpose. To have this situation improved, a method using the proportions of strain and kinetic energies to characterize the energy level of each vibration mode is proposed. With solutions of displacements, the energy distribution of each vibration mode is calculated and the mode with the highest energy concentration at a specific frequency is designated as the dominant mode. The results have been validated with the traditional approach by plotting mode shapes at each frequency. Clearly, this energy approach will be advantageous with the FEM analysis for vibration mode identification automatically.

1. INTRODUCTION

In the design of a quartz crystal resonator, it is important to make full and accurate analysis of its vibrations and to identify the functioning mode through the detailed results like frequency and mode shapes.1-4 The precise identification of vibration modes is essential because the optimal functioning mode of the resonator in the designated vibration frequency should be dominant and needs to be well isolated from so-called spurious modes of negative effects. Consequently, the functioning mode is extremely important to be identified, which is the thickness-shear mode usually, to immunize from couplings to other modes, or the notorious spurious modes. As there is no suitable way to eliminate the infinite couplings of vibration modes in a finite quartz crystal plate, it is practical to find the least coupled thickness-shear vibrations to enhance the performance characteristics of a quartz crystal resonator. In other words, the challenge is to determine the optimal parameters of the resonator structure, avoid the strong coupling of modes, and let the primary working mode be enhanced.3 In a typical resonator, the primary working mode mainly refers to the thickness-shear mode and the strongly coupled one is the flexural mode.2 For the accurate analysis of vibrations within a quartz crystal plate in the vicinity of the thickness-shear mode, the most effective method we have chosen is based on the Mindlin plate theory which can easily include more vibration modes.

The strong couplings happen just between the neighboring vibration modes, so only a few strongly coupled vibration modes are needed for the analysis to obtain the accurate results such as frequency and displacements which can be used for mode identification. Usually the analysis is done with the straight-crested waves for applications, and currently the Mindlin plate equations have been implemented in the finite element analysis for more precise considerations of structural complications. The identification of vibration modes, as from the beginning, is done with the plotting of mode shapes which show the dominance of specific mode at each frequency by picking out the largest displacement.4,5