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On the exploitation of mode localization in surface acoustic wave MEMS

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ABSTRACT

Mode localization sensing has been recently introduced as an alternative resonant sensing protocol. It has been shown to exhibit several advantages over other resonant methods, in particular a potential for higher sensitivity and rejection of common mode noise. This paper expounds the principles of utilising surface acoustic waves (SAW) to create a mode localization sensor. A generalised geometry consisting of a pair of coupled resonant cavities is introduced and an analytical solution found for the displacement fields within the cavities. The solution is achieved by coupling the internal cavity solutions using a ray tracing method. The results of the analytical solution are compared to a numerical solution found using commercial finite element method (FEM) software; exact agreement is found between the two solutions. The insight gained from the analytical model enables the determination of critical design parameters. A brief analysis is presented showing analogous operation to previous examples of mode localization sensors. The sensitivity of the device is shown to depend nonlinearly on the number of periods in the array coupling the two cavities.

1. Introduction

1.1. Mode localization sensing

Mode localization refers to the spatial trapping of energy in a coupled oscillatory system that occurs when a disorder is introduced into a previously ordered system. In the structures of interest in this article, this is manifested as a dramatic change in the mode shapes. This was first suggested as a novel sense protocol in references [1,2] and coined 'mode localization sensing'. The sense mechanism was initially proposed as an alternative to measuring frequency-shift, and therefore this method has often been used as a benchmark for comparison [2–5].

Mode localization sensors have been approached primarily in the case of two weakly-coupled symmetrical oscillators [2–5]. They exploit the large change in the eigenvector that occurs when the symmetry is broken. A simplified model of a typical mass sensor utilising this protocol is presented in Fig. 1. The identical resonators are coupled by the weak spring of strength k_c, producing a 2 degree of freedom (DOF) resonant system. In the case when $\Delta m = 0$ the system exhibits both in-phase and out-of-phase modes with equal distribution of displacement amplitude. As is commonly known, the in-phase mode is the fundamental and the out-of-phase occurs at a higher frequency. When $\Delta m \neq 0$ the modal amplitude

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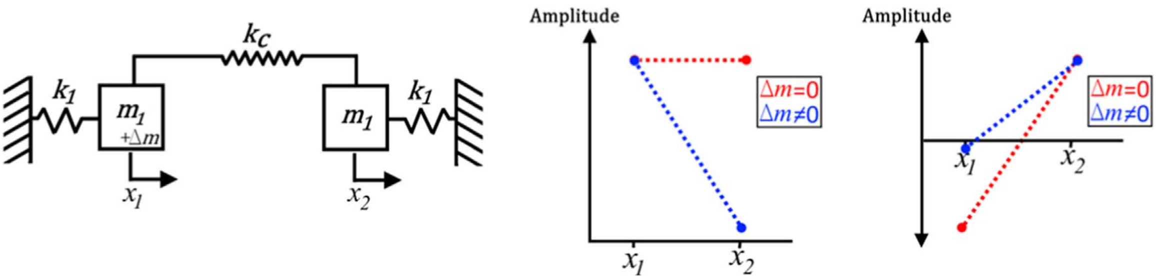

Fig. 1. Typical example of a mass sensor using the mode localization sense protocol.

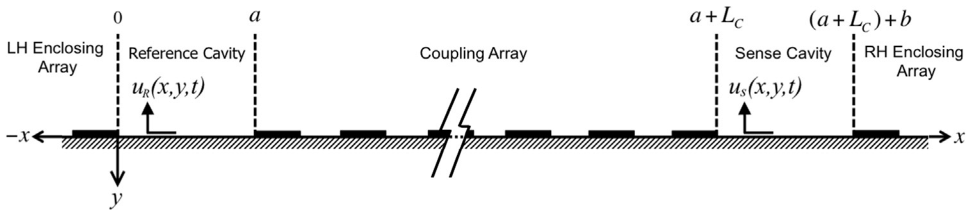

Fig. 2. Device layout schematic.

distribution is weighted unevenly, favouring the higher or lower mass DOF, in the in-phase and out-of-phase modes respectively. That is, if the system is vibrating in its fundamental mode, and a mass is added to one of the DOFs, this DOF will experience a much larger displacement relative to the other. In the second mode however, the un-laden mass will exhibit the larger relative displacement. The sensors are proposed to operate in one mode and use the ratio of the amplitude of the DOFs to detect the size of the added mass.

1.2. SAW Mode Localization Sensors

The current work extends this theory to encompass the use of periodic structures to couple the resonators. This is realised through the use of a SAW architecture. The use of SAW presents many advantages when compared to the alternative of constructing periodic arrays of suspended MEMS. The SAW devices require a simple and inherently robust architecture; there are no deep cavity etches or slender beams. The manufacturing process is well established and SAW resonators are commonplace in microelectronics. The use of SAW was introduced in micro-scale electronic filters as a low noise alternative to lumped-parameter and bulk acoustic wave filters [6]. Therefore, the use of SAW presents a favourable platform to introduce a novel sense protocol, with the potential of yielding high signal-to-noise ratio devices. The authors introduced the concept of a SAW mode localization sensor in reference [7] and to their knowledge this is the first example available in the literature.

The proposed configuration consists of two cavities, coupled by an N-period reflective array. The arrays are constructed from a patterned metal film deposited on a piezoelectric substrate. In the general case, excitation can occur in either cavity, or both cavities. Regardless of the excitation method, one cavity is deemed the reference and the other the sense cavity. The coupling strength between the two cavities is governed by the shared periodic reflector, deemed the ‘coupling array’. The basic arrangement is depicted in Fig. 2.

The output of the device is the ratio of the sense cavity displacement amplitude to the reference cavity displacement amplitude. The theory of operation is directly analogous to the mode localization sensors described in Section 1.1: the output responds in proportion to a break in the symmetry of the structure, in this case, a perturbation of the wave-speed of the sense cavity. The output response is proportion to both the perturbation size and the coupling strength.

The main body of this paper is presented in Section 2, the premises and assumptions are outlined prior to the presentation of the full derivation of the analytical model. Section 2.2 outlines the geometry and boundary conditions employed in the finite element model and Section 2.3 contrasts the two models seeking validation of the analytical model. A brief analysis is presented in Section 3, in which the frequency response of the device is discussed using the results of Section 2. In addition, a qualitative overview of the envisioned device operation is described and finally conclusions are drawn.

2. Modelling

2.1. Derivation of the analytical model

Within this section, general expressions will be derived for the displacement fields within each cavity, as a function of