Journal of Sound and Vibration 424 (2018) 352–364

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Reducing mechanical cross-coupling in phased array transducers using stop band material as backing

J. Henneberg [a,c,*], A. Gerlach [a], H. Storck [a], H. Cebulla [b], S. Marburg [c]

[a] Robert Bosch GmbH, Robert-Bosch-Campus 1, 71272 Renningen, Germany
[b] Technical University Chemnitz, Professorship for Textile Technologies, Reichenhainer Str. 31/33, 09126 Chemnitz, Germany
[c] Technical University of Munich, Chair of Vibroacoustics of Vehicles and Machines, Boltzmann Str. 15, 85748 Garching, Germany

ARTICLE INFO

Article history:
Received 21 September 2017
Revised 31 January 2018
Accepted 15 March 2018
Available online XXX

Dedicated to Professor Franz Holzweißig on the occasion of his 90th birthday.

Keywords:
Local resonator
Tuned resonator
Stop band material
Acoustic metamaterial
Phased array transducer
Cross-coupling

ABSTRACT

Phased array transducers are widely used for acoustic imaging and surround sensing applications. A major design challenge is the achievement of low mechanical cross-coupling between the single transducer elements. Cross-coupling induces a loss of imaging resolution. In this work, the mechanical cross-coupling between acoustic transducers is investigated for a generic model. The model contains a common backing with two bending elements bonded on top. The dimensions of the backing are small; thus, wave reflections on the backing edges have to be considered. This is different to other researches. The operating frequency in the generic model is set to a low kHz range. Low operating frequencies are typical for surround sensing applications. The influence of the backing on cross-coupling is investigated numerically. In order to reduce mechanical cross-coupling a stop band material is designed. It is shown numerically that a reduction in mechanical cross-coupling can be achieved by using stop band material as backing. The effect is validated with experimental testing.

1. Introduction

Phased array structures of acoustic transducers are used for acoustic imaging in medical applications and for nondestructive testing. Furthermore, there are applications for 3D surround sensing. Depending on the field of use, the typical operating frequency varies in a range from lower kHz for surround sensing [1,2] up to several MHz for nondestructive testing [3] and medical applications [4]. One of the characteristic properties of these structures is the cross-coupling between single transducers. It mainly describes the undesired behavior that array elements are not working independently [5]. In several studies it has been shown that cross-coupling influences the performance of a phased array by changing its beam pattern and resulting in a loss of resolution [5–8]. In Ref. [5] a quantitative theory for cross-coupling in ultrasonic transducer arrays is presented. Surface waves in the backing and in the load medium in front of the transducers are indicated as reason for cross-coupling. This theory assumes a series of uniformly distributed, unbacked transducer elements. The cross-coupling is caused by interaction through a semi-infinite substrate, the solid load medium. In Ref. [9] a basic model and influence of cross-coupling with focus on cross-coupling included signals is given. Lamb wave A0 mode has been identified as the responsive effect for cross-coupling in a CMUT-array (capacitive micromachined ultrasonic transducer) with first order resonance at 2.3 MHz [10]. An air-coupled, low frequency phased array is presented in the studies [11]. The ultrasonic transducers are realized with piezoelectric crystals. As

* Corresponding author. Robert Bosch GmbH, Robert-Bosch-Campus 1, 71272 Renningen, Germany.
E-mail addresses: Johannes.Henneberg@de.bosch.com, johannes.henneberg@tum.de (J. Henneberg).

https://doi.org/10.1016/j.jsv.2018.03.021

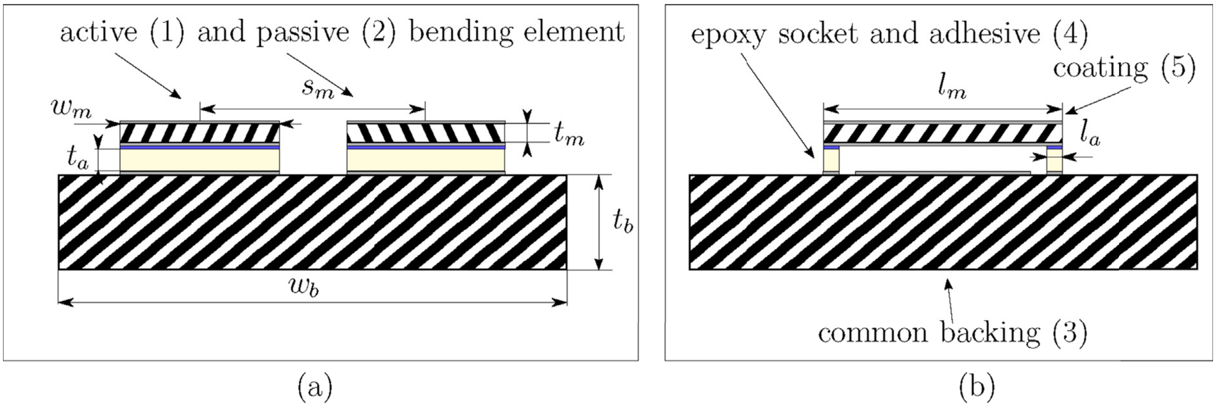

Fig. 1. Investigated generic model with 2 bending elements on a common backing. (a) frontal view, (b) side view.

the used setup with piezoelectric elements and foam as spacer does not cause high cross-coupling, it is not further investigated. In Refs. [12,13] cross-coupling is investigated in a finite element model of a linear, piezoceramic based phased array transducer.

In this study, we investigate the cross-coupling of a generic transducer array model with a low operating frequency at 5.2 kHz. We focus especially on mechanical cross-coupling caused by the common backing without extra lossy regions. The realization of extra lossy regions between every transducer element requires high effort in real structures. Thus, a design without extra lossy regions is desired. Cross-coupling caused by the common backing is the dominating effect in air-coupled transducer arrays. The dimensions of the backing are small, thus wave reflections on the edges of the backing have to be taken into account in simulations of the whole model. This is different to other researches. The design of the backing is a major challenge in phased array transducers with low operating frequency. To overcome this problem, we show that stop band materials can be used to reduce mechanical cross-coupling caused by common backing in phased array structures. Stop band materials, also known as acoustic metamaterials, consist out of periodic structure with particular dynamic behavior in a certain frequency range. Hence it is clarified that stop band material describes a structural but not a material behavior.

In recent years, stop band materials received a growing attention. In analogy to photonic crystals, Ref [14] presents a study with experimental investigation on sonic crystals to design band gap behavior. Therefore, rigid spheres of lead were coated with rubber and placed in an epoxy plate. Stop band materials can decrease acoustical [15] as well as vibrational [16] responses of components in certain frequency bands. Thus, bragg scattering and local resonant structures can be used. As Bragg scattering is based on destructive interference effects [17], a periodic lattice is required. In contrary, resonant stop bands can be achieved by ordered and disordered structures. This is shown for an electromagnetic metamaterial in Ref. [18] and for an acoustic metamaterial in Ref. [19]. However, the scale of the stop band material should be smaller than the wavelength to be attenuated. In this study, ordered periodic resonant structures are investigated. In Ref. [15], it is shown that resonant stop bands have a good prospect for low frequency stop bands. In Ref. [20], it is shown that propagation of flexural waves in thin plates can be attenuated by locally attached spring-mass resonators. In Ref. [21], a possible application for microfabricated phononic crystal waveguides is named but not investigated in detail. The intention is to route and bend acoustic signals from large electro-acoustic transducers to be emitted and detected through small apertures. By this, the resolution of phased array structures can be increased.

Initially we focus on a generic model to investigate the relation between dynamical behavior of the backing and cross-coupling. In finite element simulation, we analyze the dependence of cross-coupling on the backing thickness. Afterwards, we investigate an extended model with stop band material as backing. In simulation as well as in experimental testing, the effect of locally resonant structures with regard to mechanical cross-coupling is shown. Finally, a conclusion is drawn.

2. Cross-coupling in phased array transducer

In this section we give an overview of the investigated generic model. The calculation of cross-coupling is defined and its mechanism is shown for the generic model.

2.1. Generic model setup

In analogy to CMUT-arrays, a generic model is set up with two bending elements bonded on a square, common backing. Each bending element forms an electrode of a capacitive transducer. The counter-electrodes are realized on the common backing. To achieve electrical conductivity, the bending elements and the backing are coated with aluminum (5). The cross-section of this generic model is shown in Fig. 1. The two bending elements (1 + 2) are made of carbon fiber reinforced plastic (CFRP) coated with aluminum. They are bonded with a cyanoacrylate adhesive to epoxy sockets (4) on a common epoxy backing (3).

The dimensions are given in Table 1. This setup is comparable with the setup up given in Ref. [10]. The main differences are