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Least-squares reconstruction of low-frequency inhomogeneous plane waves

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ABSTRACT

Through the use of linear acoustic source arrays, it is possible to generate sound fields with a specified pressure distribution at a given standoff distance. By specifying the desired pressure at a number of points on a target surface, the powers and relative phases of the sound sources can be tuned to generate a least-squares reconstruction of a desired pressure distribution. While this method of sound field reconstruction has been explored for homogeneous waves, here its application to the generation of inhomogeneous plane waves, or waves that decay spatially in a direction perpendicular to their direction of propagation, will be analyzed. Models of the pressure field created from many sources will be applied to determine the effects of altering certain array parameters, such as the standoff distance and the source spacing, on the maximum pressure error and total acoustic power consumption. These figures of merit will be compared to similar values for homogeneous plane waves to elucidate the effect of inhomogeneity on sound field reconstruction. The extent to which imprecision at the source affects the observed inhomogeneity will be discussed, as proper tuning of the decay parameter is critical to minimizing the reflection coefficient of an inhomogeneous plane wave incident on a surface.

1. Introduction

The efficient transmission of low-frequency acoustic energy into solid materials may prove useful in a number of applications, as the low attenuation coefficients in air at lower frequencies [1,2] allow for appreciable standoff excitation distances. Examples of such applications include the nondestructive evaluation of structures [3,4], where excitation is generally implemented by contact transducers, and the inspection of food products [5,6], where the use of a couplant is undesirable. However, the transmission of incident acoustic energy into solids is typically hampered by the reflection and refraction at the fluid–solid interface [2,7,8]. This is attributable to the large impedance difference between the fluid and solid media. In order to address this limitation, previous work has involved the use of incident inhomogeneous plane waves, and it was demonstrated that, by tuning the incidence angle and inhomogeneity, small reflection (and large energy transmission) values are predicted in the context of lossless and low-loss fluid–solid interfaces [9,10]. It is the goal of the present work to investigate acoustical source array techniques for the reconstruction of such inhomogeneous plane waves, with the aim of enhancing energy transmission into target solid media.

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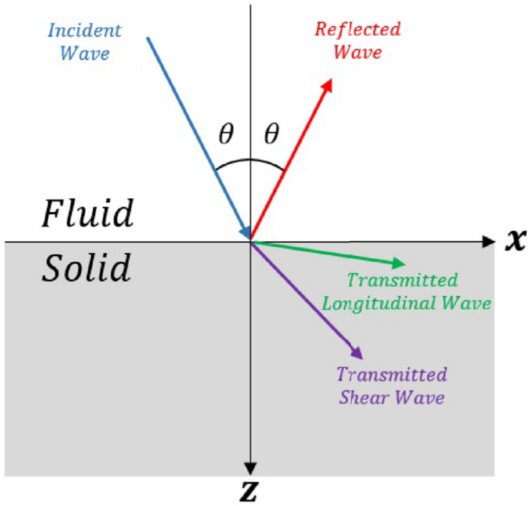

Fig. 1. A diagram showing the interaction of a plane wave incident on a fluid–solid boundary.

Methods for the reproduction of arbitrary sound fields, including plane waves and random pressure fields, have been described in detail in a wide variety of contexts [11–18]. Commonly employed techniques include the least-squares method [13], the wave field synthesis approach [14], and the spectral division method [15,17]. In the least-squares method, the desired pressure field is specified at a discrete number of points (e.g., on a receiver plane) and the least-squares algorithm is utilized to compute the source strengths (amplitudes and phases) for a specified number of sources and source locations [13]. Inevitably, a finite number of sources are used, and the generated pressure field is in error relative to the desired field, with that error depending on the nature of the desired field, the standoff distance, and the parameters which characterize the source and receiver arrays [13]. Moreover, errors in the regions between the receivers also occur (for a continuous desired pressure distribution), since a finite number of receivers are used in the solution algorithm.

In the context of inhomogeneous plane waves, which are investigated here as profiles which may enhance energy transmission into solid materials, approximations to such plane wave fields have, in fact, been previously generated [16,19–22], and the reflection phenomena at solid interfaces have been documented in relation to plane wave theory [21]. However, no previous work has reported tuning the inhomogeneity in order to enhance energy transmission. It is thus the purpose of this work to apply the least-squares method for sound field reconstruction, using one-dimensional linear source and receiver arrays, to reproduce inhomogeneous plane wave fields over a range of inhomogeneity values. In particular, the source spacing will be varied to find values which simultaneously yield low errors in the generated pressure and low power consumption requirements over orders of magnitude of the incident wave inhomogeneity, which will make the array robust for a large range of incident

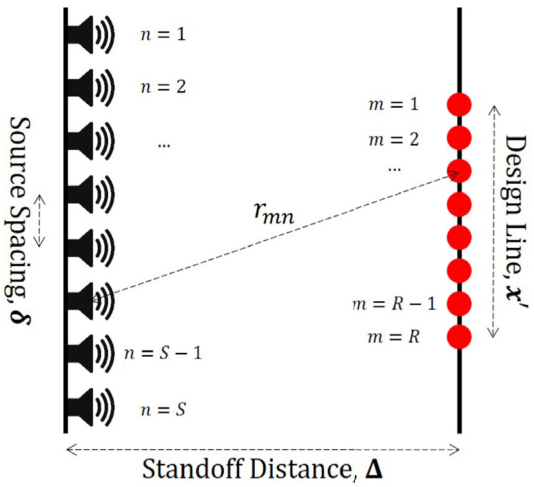

Fig. 2. A diagram showing the one-dimensional linear source and receiver arrays.