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Sloshing-based low-frequency tonotopic meta-structures

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Extended Abstract

Abstract

Mechanical metamaterials and metastructures are well known mainly for their dispersive behaviour and for the possibility to filter and/or stop signals in specific frequency ranges. The possibility to create rainbow or tonotopic effects by means of gentle grading of some geometric properties, as for instance shown in [1], has more recently attracted increasing attention. The focus of the present work is on the scarcely explored potentialities offered by solid-liquid interaction and by the synergistic activation of solid, liquid and/or hybrid modes in solid-liquid meta-structures fabricated by means of additive manufacture. Starting from the work discussed in [2], where the sloshing modes of the free surface of a fluid open a bandgap at low frequencies, we numerically explored the tonotopic behaviour of an array of similar cells with graded side. In the chosen configuration, the role of the liquid is double: it acts as an added mass shifting the dispersion curves towards lower frequencies and introduces local resonances at low frequencies, related to the sloshing modes of the free surface. The position of these resonances can be controlled by changing the size of the free surface. In this way, precise shifting of the dispersion curves can be obtained, which is promising for easy to fabricate tonotopic sensors working at very low frequency, not requiring precisely tuned thin elements and small enough to be compatible with common 3D printers. Connecting

multiple cells with different resonances to form a graded array, it is possible to activate local modes in specific parts of the array depending on the frequency of the excitation, allowing for simple measurement of the input frequency. To detect the activation of sloshing modes, cantilevers were added under the free surface of each cell, put in motion by the fluid surface waves. It is shown that the activation of the cantilever is narrowly peaked around the natural frequencies of sloshing, which is promising for the development of tonotopic sensors. The dispersion and transmission properties of the designed array were studied using Finite Elements in the frequency domain with acoustic elements for the liquid phase and an acoustic impedance on the free surface [3]. To account for losses in the interaction between the phases, a thermo-viscous model of the liquid (with Linearized-Navier-Stokes) was used; it was shown that higher modes inefficiently transfer energy to the solid, which would be useful for increasing the sensing range by suppressing signals at undesired frequencies.

Keywords:

Metastructures Solid-liquid interaction Tonotopicity

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