Design of acoustic metamaterial using level set-based topology optimization

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Abstract

We present a level set-based topology optimization method for the design of an acoustic metamaterial consisting of elastic and acoustic materials, incorporating sensitivity analysis based on the concept of the topological derivative.

In acoustic-elastic coupled systems, including acoustic metamaterials, acoustic and elastic waves are coupled. That is, the acoustic waves operate as oscillating forces on the surface the elastic material, and elastic waves propagating in the elastic material generate acoustic waves that propagate in the acoustic material. Lu et al. [1] investigated optimal designs for acoustic metamaterials, but this coupling effect was ignored. However, unless the coupling effect is considered, the obtained designs seldom manifest the desirable and unusual properties of acoustic metamaterials when fabricated.

To represent an acoustic elastic coupled system, we introduce a two-phase material model, in which the solid and fluid phases are mixed. Since the acoustic-elastic coupling effect occurs at the boundaries between the acoustic and elastic domains, analysis of an acoustic-elastic coupled system usually requires the imposition of coupling boundary conditions at the boundaries. This procedure complexifies the numerical implementation and increases computational costs because coupling boundaries move and may be generated or removed during the topology optimization process. On the other hand, the proposed two-phase material model expresses the acoustic-elastic coupled system uniformly and coupling conditions at the boundaries are therefore not required, so the model is easily applied in a topology optimization.

Sensitivity analysis is performed in the two-phase material model based on the concept of the topological derivative, obtained by first calculating the shape derivative and then taking its limit to derive the topological derivative.

In this research, the two-phase material model that represents the acoustic-elastic coupled system is introduced first. Next, the level set-based topology optimization method is discussed [2]. After formulating the optimization problem to obtain the design of an acoustic metamaterial that exhibits a negative bulk modulus, we present the method for calculating the topological derivative of the two-phase material model. Finally, two-dimensional design examples demonstrate the validity of the proposed method.

Keywords: Topology optimization, Level set method, Acoustic-elastic coupled system, Two-phase material model, Acoustic metamaterial, Topological derivative.

References

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