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Shape design sensitivity analysis for the radiated noise from the thin-body

Jeawon Lee, Semyung Wang*

Department of Mechatronics, Kwangju Institute of Science and Technology, 1 Oryong-dong, Puk-gu, Kwangju 500-712, South Korea

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Abstract

Many industrial applications generally use thin-body structures in their design. To calculate the radiated noise from vibrated structure including thin bodies, the conventional boundary element method (BEM) using the Helmholtz integral equation is not an effective resolution. Thus, many researchers have studied to resolve the thin-body problem in various physical fields. No major study in the design sensitivity analysis (DSA) fields for thin-body acoustics, however, has been reported.

A continuum-based shape DSA method is presented for the radiated noise from the thin-body. The normal derivative integral equation is employed as an analysis formulation. And, for the acoustic shape design sensitivity formulation, the equation is differentiated directly by using material derivative concept. To solve the normal derivative integral equation, the normal velocities on the surface should be calculated. In the acoustic shape sensitivity formulation, not only the normal velocities on the surface are required but also derivative coefficients of the normal velocities (structural shape design sensitivity) are also required as the input. Hence, the shape design sensitivity of structural velocities on the surface, with respect to the shape change, should be calculated. In this research, the structural shape design sensitivities are also obtained by using a continuum approach. And both a modified interpolation function and the Cauchy principle value are used to regularize the singularities generated from the acoustic shape design sensitivity formulation.

A simple annular disk is considered as a numerical example to validate the accuracy and efficiency of the shape design sensitivity equations derived in this research. The commercial BEM code, SYSNOISE, is utilized to confirm the results of the developed in-house code based on a normal derivative integral equation. To validate the calculated design sensitivity results, central finite difference method (FDM) is employed. The error between FDM and the analytical result are less than 3%. This comparison demonstrates that the proposed design sensitivities of the radiated pressure are very accurate.

*Corresponding author. Tel.: +82-62-970-2390; fax: +82-62-970-2384.
E-mail address: smwang@kjist.ac.kr (S. Wang).

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1. Introduction

Thin-body structures are frequently used for the design of many industrial applications such as fins or opened shells. To solve the acoustic problem including thin bodies, the conventional boundary element method (BEM) using the Helmholtz integral equation is not an effective resolution because the mesh on one side of a thin-body is too close to the mesh on the opposite side. Although that difficulty can be overcome by using very fine meshes, the process requires too much preprocessing and calculation time. Moreover, the nearly singular problem may occur in the integral equation. Thus, many researchers have tried to solve the thin-body problem in various physical fields including acoustics, electromagnetics and solid mechanics.

The multi-domain BEM [1] is the simplest way to handle the thin-body problem theoretically. Even though the concept of multi-domain BEM is simple and straightforward, it is not very efficient in computation when the imaginary interface surface is relatively large. In the normal derivative integral equation, proposed by Wu and Wan [2], an imaginary interface surface is also constructed like the multi-domain BEM. Furthermore, the Helmholtz integral equations and the normal derivative integral equations are constructed for each subdomain including both a structural surface and an imaginary surface. The integrals over the imaginary interface surface, however, are simply canceled out due to continuity of pressure and velocity after combining the Helmholtz integral equations with its normal derivative equation. Therefore, only the neutral surface of the thin-body remains for the discretization. The normal derivative integral equation approach, however, involves the evaluation of a hyper-singular integral in order of $1/r^3$. So the regularization method, originally derived by Maue [3] and later by Mitzner [4], is utilized. The evaluation of the hyper-singular integral can be also avoided by adopting a variational formulation, proposed by Pierce et al. [5] The resulting coefficient matrix obtained from the variational formulation is symmetric, but the computational cost is relatively high because a double surface integral must be evaluated.

In the area of the design sensitivity analysis (DSA) for acoustics, not many studies have been reported by using the BEM. Kane et al. [6] presented a shape design sensitivity formulation method by using the implicit differentiation of the discretized Helmholtz integral equation. Koopmann et al. [7] studied the sensitivity of radiated acoustic power to the change of acoustic velocity for a given geometric configuration. Vlahopoulos [8] and Coytte et al. [9] also studied the sizing DSA of acoustic radiation problems. Smith and Bernhard [10] computed the sensitivity by differentiating the discretized boundary integral equation. The derivative of the system matrix was approximated by adopting the finite difference concept. Cunefare et al. [11,12] presented sizing acoustic DSA through chain-ruled derivatives from FEM and BEM codes. Their research had focused on the best optimization formulation by comparing the relative performance and results obtained through the use of several different objective functions and constraints. Bonnet [13,14] derived continuum differentiation of the conventional boundary integral equation. Wang and Lee [15] presented a sizing acoustic DSA method using a continuum approach.

In this research, a continuum-based shape DSA method is presented for the radiated noise from a thin-body. The normal derivative integral formulation is differentiated directly by using material derivative concept to get the acoustic shape design sensitivity. And the shape design sensitivities of structural velocities on the surface are also calculated with the continuum approach. As a