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STRUCTURE-MODIFIED INFLUENCE ON THE INTERIOR SOUND FIELD AND ACOUSTIC SHAPE SENSITIVITY ANALYSIS

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The covering-domain method is adopted to calculate first the interior sound field of a complex-shaped cavity stiffened with stringers, then the influence of an appended mass on the complex cavity wall is further analyzed based on the covering-domain method. Besides, the method is applied to analyze acoustic shape sensitivity of complex-shaped cavity. Combining a specific cavity, we calculate the corresponding acoustic shape sensitivity when every dimension of the cavity varies respectively. This will provide theoretical instruction for dynamic structural modification of the complex-shaped cavity.

1. INTRODUCTION

The interior sound field distribution of a cavity could be optimized or altered by dynamic structural modification in general. There are many optimizing measures in common use, such as appending stiffened stringer or a piece of mass, recomposing structural restrictions and altering wall-thickness or shape of the cavity. It is of important practical significance to analyze structure-modified influence on the interior sound field quantitatively.

For a complex-shaped closed shell, the substructure method [1] can be used to analyze the influence of stiffened stringer. But the method needs to obtain the mass, rigidity and damping matrixes of every subsystem, and to calculate eigenvalue of large matrix, which is time-consuming despite some mature arithmetic, such as sub-space method and Lanczaos method.

According to the principle of the covering-domain method [2, 3], it can be applied not only to calculate the interior sound field of complex-shaped cavity, but also to deal with the complex cavity with uneven wall-thickness. Therefore, in this paper, the covering-domain method is used to analyze the influence of a stiffened stringer on the internal sound field of the complex cavity, and further to study the influence of an appended mass.

In addition, acoustic shape sensitivity analysis is studied by adopting the covering-domain method in this paper.

Early in 1988, Aria *et al.* [4] analyzed acoustic shape sensitivity without considering vibroacoustic coupling. In 1991, Kane *et al.* [5] presented a shape design sensitivity analysis formulation by using the implicit differentiation of the discretized Helmholtz integral equation. In 1992, Smith and Bernhard [6] computed the sensitivity by differentiating the

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discretized boundary integral equation. The derivative of the system matrix was approximated by adopting the finite difference concept. Although the finite difference method is straightforward and easily available for utilization, the method is not suitable for non-linear systems and has high computational cost owing to the reconstruction of the system matrix in order to adapt it for the perturbed shape.

In order to reduce the singularity of the sensitivity equation, the uniform potential field is brought into the solution process [7]. Because this potential-combined weakly singular sensitivity equation can increase the computational cost and requires singular integration to obtain an accurate solution, the sensitivity equation is further regularized and only the acoustic equation is used. The singularities of the integrands in the integral representation can be removed by adopting an integral identity utilizing the one-dimensional propagating wave component.

Therefore, we adopt the covering-domain method to analyze the acoustic shape sensitivity of the complex-shaped cavity, which has direct significance of optimizing its inside sound field by altering the structural shape.

2. THEORY OF THE COVERING-DOMAIN METHOD

Assume that the elastic objects A and B are, respectively, fixed in two separate co-ordinate systems. When the two co-ordinate systems are overlapped, it is concluded that B covers A if point $M \in A$, then $M \in B$.

In the general case, the boundary curved surface C of an arbitrary-shaped closed shell A can always be fitted by n pieces of spherical surfaces $C_1, C_2, \ldots, C_n$. To calculate the interior sound field of the closed shell A, a series of close spherical shells A_k ($k = 1, 2, \ldots, n$) can be used to cover A. The spherical shell A_k has only a piece of its boundary L_k to coincide with C_k and has the same thickness as the original spherical surface C_k. It is obvious that the common domain of all of A_k is the domain occupied by the closed shell.

Although it is difficult to calculate the interior sound field of a closed shell with complicated shape directly, it is easy to calculate the interior sound field of these spherical shells. So we can make use of the concept of covering-domain to change the problem of the interior sound field of a complicated shell into a simple problem of a series of closed spherical shells. Then the interior scattered sound field of the arbitrary-shaped closed shell can be expressed as follows:

$$P_S(\mathbf{r}) = \sum_{k=1}^{n} P_{SS}^{(k)}(\mathbf{r}), \tag{1}$$

where $P_{SS}^{(k)}(\mathbf{r})$ is the scattering sound field of the kth covering spherical shell at a point $\mathbf{r}$ inside the arbitrary-shaped closed shell.

According to references [2, 3], when there is a point sound source with unit strength at a point $\mathbf{r}_0(r_0, \theta_0, \varphi_0)$ inside a closed thin spherical shell, then the scattered sound pressure at an interior point $\mathbf{r}(r, \theta, \varphi)$ can be expressed as

$$P_{SS}(r, \theta, \varphi) = \sum_{n=0}^{\infty} \sum_{m=-n}^{n} C_n \, \mathrm{j}_n(kr) P_n^m(\cos\theta)\, \mathrm{e}^{\mathrm{i}m\varphi}\, \mathrm{e}^{-\mathrm{i}\omega t}, \tag{2}$$

where

$$C_n = \frac{b_{n1}}{a_{n2}} \frac{\mathrm{i}\omega}{4\pi c}(2n+1)\frac{(n-m)!}{(n+m)!} P_n^m(\cos\theta_0)\, \mathrm{e}^{-\mathrm{i}m\varphi_0}\, \mathrm{j}_n(kr_0),$$