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Development of indirect EFBEM for radiating noise analysis including underwater problems

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ABSTRACT: *For the analysis of radiating noise problems in medium-to-high frequency ranges, the Energy Flow Boundary Element Method (EFBEM) was developed. EFBEM is the analysis technique that applies the Boundary Element Method (BEM) to Energy Flow Analysis (EFA). The fundamental solutions representing spherical wave property for radiating noise problems in open field and considering the free surface effect in underwater are developed. Also the directivity factor is developed to express wave's directivity patterns in medium-to-high frequency ranges. Indirect EFBEM by using fundamental solutions and fictitious source was applied to open field and underwater noise problems successfully. Through numerical applications, the acoustic energy density distributions due to vibration of a simple plate model and a sphere model were compared with those of commercial code, and the comparison showed good agreement in the level and pattern of the energy density distributions.*

KEY WORDS: Energy flow boundary element method (EFBEM); Radiating noise; Free surface effect; Directivity factor.

INTRODUCTION

When ships or underwater objects move through water, whose impedance is much higher than that of air, small vibrating motions of the inner ship body can cause remarkable noises in wide frequency ranges. No single analysis method of the noise phenomenon can be effectively applied to all ranges of noise problems. At low frequency ranges, the analysis of vibration problems is analyzed by the conventional methods such as the Finite Element Method (FEM) and Boundary Element Method (BEM). But, at high frequency ranges, those methods require more computation time and costs, and thus alternative methods are needed.

Among many alternative methods, EFA has received much attention. This method was introduced by Belov et al. (1997) in 1997. Nefske and Sung (1989) implemented Energy Flow Finite Element Method (EFFEM) to solve the transverse vibration of a beam. Wholever and Bernhard (1992) derived the energy governing equation for diverse vibrating waves of a beam. Bouthier and Bernhard (1992) derived the energy governing equation of a flexural wave, considering only the far-field component of the transverse vibration of a membrane and thin plate. They expanded the research of EFA to vibration problems of two-dimensional structures. Cho (1993) researched the energy boundary condition in the connection point between elements of a beam by applying the wave transmission approach to a complex structure. Park (1999) and Park et al. (2001) derived the energy governing equation for an in-plane wave of a thin plate and studied the spatial distribution and transmission path of vibration energy for a plate structure, which is connected at a non-determined angle. Seo et al. (2003) expanded the application of EFA to

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beam-plate coupled structures. Lee et al. (2008) applied EFBEM to the vibration analysis of beam and plate problems. Also Wang et al. (2004) applied energy boundary element formulation to the sound radiation problems.

In this paper, the energy governing equation having spherical wave property is developed in open field. And the directivity effect which is represented in high frequency range problems but can't express in EFA is studied. And the fundamental solution and energy governing equation for underwater problems are developed. The developed equation and directivity effect are applied to the simple case and the results are compared with commercial noise analysis program, SYSNOISE and reliable results are obtained.

ENERGY GOVERNING EQUATION FOR RADIATING NOISE ANALYSIS

Energy balance equation

In a linearly elastic medium, the energy balance equation is derived from the following Eq. (1). The amount of incoming and out coming power through the surface of an object and the rate of change of the total energy in the object are same. From this fact, energy balance equation is represented as follows:

$$\iiint_{CV} \frac{\partial e}{\partial t} dV = \iint_{CS} \left(\sigma \cdot \frac{\partial \vec{\xi}}{\partial t} \right) \cdot d\vec{\mathbf{S}} + \iiint_{CV} (\pi_{in} - \pi_{diss}) dV \tag{1}$$

where, e is the total energy density in the volume of an object, CV. $\vec{\xi}$ is the displacement vector at the boundary of an object, CS. $d\vec{\mathbf{S}}$ is a small area vector perpendicular to the surface of the boundary. σ represents the stress on the surface of the boundary. π_{in} and π_{diss} are expressed as input power and loss power acting on a unit volume at a unit time, respectively. Intensity, defined as the power per unit area flowing out of an object, can be obtained from the stress acting on the surface of the boundary and the velocity of the surface of the boundary as follows:

$$\vec{\mathbf{I}} = -\sigma \cdot \frac{\partial \vec{\xi}}{\partial t} \tag{2}$$

where, $\vec{\mathbf{I}}$ is the intensity, the power per unit area. In Eq. (1), the first integral on the right hand side is rewritten with the application of Gauss's theorem as follows:

$$-\iint_{CS} \left(\sigma \cdot \frac{\partial \vec{\xi}}{\partial t} \right) \cdot d\vec{S} = \iint_{CS} \vec{\mathbf{I}} \cdot d\vec{\mathbf{S}} = \iiint_{CV} (\nabla \cdot \vec{\mathbf{I}}) dV \tag{3}$$

Therefore, the energy balance equation in the volume of an object is obtained by

$$\iiint_{CV} \frac{\partial e}{\partial t} dV = \iiint_{CV} (\pi_{in} - \pi_{diss} - \nabla \cdot \vec{\mathbf{I}}) dV \tag{4}$$

From Eq. (4), the energy balance equation for a small volume is expressed by

$$\frac{\partial e}{\partial t} = \pi_{in} - \pi_{diss} - \nabla \cdot \vec{\mathbf{I}} \tag{5}$$