Location Optimization of Monopole Equivalent Sources in Wave Superposition Method

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In wave superposition method, the prediction accuracy of acoustic pressure heavily depends on the locations of equivalent sources. In this paper, the prediction accuracy corresponding to monopole equivalent source is studied. According to analysis in this paper, when the velocities on some boundary nodes are inversely calculated using the predicted pressures, there is velocity reconstruction error, and the prediction error of the acoustic pressure and the velocity reconstruction error are closely related. The relationship between them is theoretically derived and indicates that the prediction error decreases with a decrease in velocity reconstruction error. Based on these findings, a method to determine the optimal locations by minimizing the normalized velocity reconstruction error is proposed. A frequency threshold criterion is devised to give the frequency range for certain number of equivalent sources within which good prediction accuracy of the acoustic pressure can be obtained. The proposed method is validated by simulation and experiment, respectively. The results show that the method significantly reduces prediction errors and is feasible.

1. INTRODUCTION

Boundary element method (BEM) is established as a well-known numerical tool for predicting acoustic pressure in infinite domain. In the BEM, boundary surface discretization is only required, and the Sommerfeld radiation condition at infinity is naturally satisfied.\(^1\)-\(^3\) However, the system matrices of BEM are usually non-sparse and non-symmetric, which increases the processing time and storage requirements.\(^2\) Furthermore, the non-uniqueness problem occurs at characteristic wave numbers corresponding to interior problems.\(^2\),\(^3\) Different methods including the CHIEF and the Burton-Miller methods to overcome the non-uniqueness problem have been devised.\(^1\)-\(^4\) In the CHIEF method, the integral formulation is modified by adding equations to enforce solutions to vanish at points in the interior. Thus, the fictitious solutions can be differentiated from the true ones. But there is a lack of rigorous criteria for selecting interior points and determining the limit of stability.\(^3\) The Burton-Miller method, in which the integral equation is combined with its normal derivative, theoretically precludes non-unique solutions. However, the various orders of singular integrals of Green’s function must be numerically described and can lead to inefficiencies in computation.\(^4\) During the past few decades, tremendous progresses in the development of BEM are moving the application of BEM in predicting acoustic radiation in infinite domain. For example, with the recent developments in fast multipole BEM, the computational efficiency is significantly improved.\(^5\) The relevant work of BEM is still on its way.\(^6\)-\(^9\)

Koopmann et al. proposed the wave superposition method (WSM) based on the idea that the radiated acoustic field of a radiator can be constructed as a superposition of the fields generated by an array of equivalent sources located on an auxiliary surface in the radiator.\(^10\) The source strengths are determined by the specific normal velocity distribution on boundary surface. Thus, the singular integrals of Green’s function,\(^4\),\(^11\)-\(^14\) which are involved in BEM when the acoustic pressure prediction points are located on the boundary surface, are eliminated. Only matrix operations are needed for the acoustic pressure prediction. Therefore, this method greatly simplifies the process of acoustic pressure prediction and is easily realized using computer programming. WSM has been applied to calculation of acoustic radiation.\(^15\)-\(^17\) However, the prediction accuracy of acoustic pressure using this method strongly depends on the locations of the equivalent sources, particularly for the radiators with complex geometric shapes. Determining the locations becomes a problem. If the sources are far from the boundary surface, the system equations become ill-conditioned and the prediction accuracy of acoustic pressure is greatly affected. Alternatively, if equivalent sources are located near the boundary surface, the singularity occurs and erroneous predicted results will be obtained. The equivalent source locations are distinguishing for different structures. These lead to that until now there is no available commercial software of WSM to predict acoustic pressure.

To determine the equivalent source locations, some researches have been proceeded. Bai provided an effective methodology for finding the optimal distance for WSM ap-