

Application of Inverse Boundary Element Method for Far Field Sound Pressure Prediction of a Diesel Engine

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ABSTRACT

This paper presents an approach to predict the far field sound pressure for a diesel engine using the inverse boundary element method. In this approach, near field sound pressure is measured first. The particle velocity is then reconstructed to a virtual plane instead of the actual vibrating surfaces and the far field sound pressure can be predicted using the reconstructed particle velocity of the virtual plane. Two sets of inverse sound pressure are employed to validate the approach. One is from the finite element and boundary element methods. The other is from the sound pressure measurement of a diesel engine in a hemi-anechoic chamber. Good correlations between the predicted and the measured sound pressure demonstrate that the method can be used to accurately predict the far field sound pressure.

INTRODUCTION

The trucks in the United States of America are required to meet pass-by noise regulation. In order to meet the regulation, various sound treatments have been applied to engines and vehicles. Common noise reduction solutions include stiffening the engine block, adding oil pan sound barrier, applying damping patches on the engine and underhood sound-absorbing material treatments. Thus numerous pass-by noise tests need to be conducted to evaluate the impact of those noise treatments on the pass-by noise of a vehicle. However, the process of the pass-by noise testing on a test track can be costly and time-consuming.

The inverse boundary element method (IBEM) can be employed to reconstruct the surface/particle velocity of a vibrating object using measured sound pressure data at the near field. Then the sound pressure at the acoustic field and the sound power of the vibrating object can be calculated

using the reconstructed surface velocity. Also, the reconstructed surface vibration allows us to conduct contribution analysis and obtain sound source ranking. Originally, this technique is used for acoustic source identification. The other application area of this technique is to predict the far field sound pressure using the measured near field sound pressure [1]. The technique may also be used for pass-by sound pressure prediction at the far field using measured sound pressure in a test cell or an open field to shorten the testing time and reduce the testing cost.

In this project, the methodology is validated in the test cell with a diesel engine running at a low RPM. Generally, for the IBEM, the measurement points plane (surface) needs to be very close to the vibrating object to obtain accurate reconstructed vibrations. Sometimes this may not be practical due to high temperature of the object, high air flow or the packaging of the engine. In this study a virtual vibrating plane is employed as a reconstruction surface instead of using the surface of the actual vibrating object.

Regarding the IBEM, Herrin et al. used the method to predict the far field sound pressure for a generator set. Their results show that the IBEM can be used to accurately predict the sound pressure as far away as 7 meters from the source up to 3500 Hz [1]. Martinus et al. explored the use of the IBEM in identifying aeroacoustic noise sources. The sound pressure was measured at the locations out of the flow field and the acoustic response can be predicted using the IBEM, including the flow field [2]. Ando et al. employed the IBEM to solve the problem of high-frequency gear whine noise [3]. There are more applications of the IBEM at automobile industry [4], [5], [6].

In this paper, the methodology is first validated using the calculated sound pressure from NASTRAN and SYSNOISE.

Then the method is applied to predict the far field sound pressure of a diesel engine in a hemi-anechoic chamber from the measured sound pressure.

THE INVERSE BOUNDARY ELEMENT METHOD

The pressure $\{p\}$ at field points can be related to any surface normal vibration $\{v_b\}$ via

$$\{p\} = [ATM]\{v_b\}, \quad (1)$$

where $[ATM]$ is the acoustic transfer matrix, $\{p\}$ is the field sound pressure and $\{v_b\}$ is the surface normal velocity. The $[ATM]$ is a matrix of transfer functions which relate the surface normal velocity of the vibratory structure to the sound pressure in the field. The $[ATM]$ can be measured but it is most commonly determined using the boundary element method (BEM).

The goal of the inverse boundary element method is to obtain the surface normal velocity $\{v_b\}$ using measured sound pressures $\{p\}$ in the acoustic field. Since the number of sound pressure measurements is generally much less than the number of the unknown surface velocity nodes, the inverse problem is an under determined problem. The inverse problem to determine the $\{v_b\}$ using known $\{p\}$ is normally computed via singular value decomposition (SVD) algorithm. The accuracy of the inverse reconstruction depends on the condition of the acoustic transfer matrix $[ATM]$, measurement point selection, and measurement and modeling errors. [Reference \[8\]](#) details guidelines for selecting measurement positions.

FAR FIELD SOUND PRESSURE PREDICTION USING CALCULATED SOUND PRESSURE

For the IBEM, the selection of the measurement points affects the accuracy of the prediction [1]-[2]. The distance between the sound pressure measurement point and the vibratory object is suggested to be roughly within one wavelength of the maximum interesting frequency [8]. At high frequency, this can be very small. For example, with a maximum interesting frequency of 3000 Hz and air speed of sound of 343 m/s, the distance is about 0.11 meter. However, for the diesel engine, this may not be practical due to the high temperature of the engine surface, high air flow and the engine packaging.

In this study, our interest is the far field sound pressure prediction. Therefore, a virtual reconstruction plane which is close to the measurement point plane could be employed for particle velocity reconstruction. Then the far field sound

pressure prediction can be conducted using the reconstructed particle velocity at the virtual plane.

In order to validate the approach at an ideal condition, a white-noise force excitation is applied to the engine block at the center of a main bearing. Sound pressure at the near field is computed using the finite element method (FEM) and the BEM. Then the sound pressure is used for inverse calculation. The models used in the BEM simulation is shown in [Figure 1](#), which include a diesel engine block, a virtual plane and a measurement point plane.

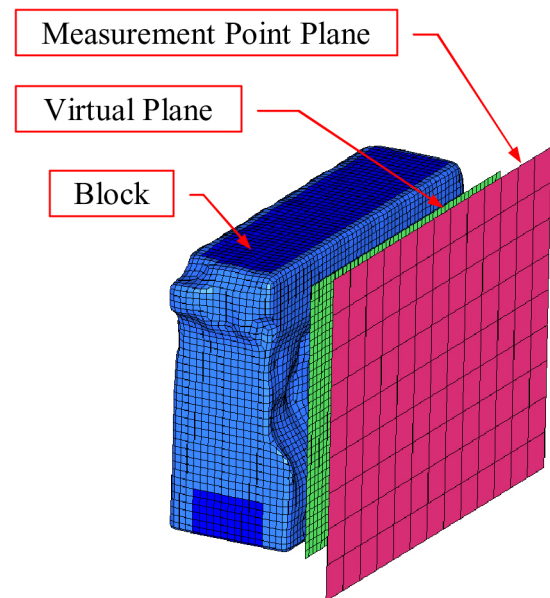


Figure 1. BEM models: a diesel engine block, a virtual plane and a measurement point plane

Using the previously calculated inverse pressure at the measurement point plane, the surface (particle) velocity is reconstructed on the block and the virtual plane, respectively. [Figure 2](#) shows the inverse pressure on the measurement point plane and the reconstructed surface velocity on the block at 200 Hz.

The sound pressure at the far field (15 meters away from the block for this case) is calculated using (1) the original surface velocity of the block from the FEM, (2) the reconstructed surface velocity on the block from IBEM and (3) the reconstructed surface velocity on the virtual plane from the IBEM, respectively. The result from (1) is considered as accurate. The predicted far field sound pressure results using these three approaches are compared in [Figure 3](#). It can be noted that the sound pressure results from all the three approaches agree reasonably well cross the whole frequency range (200 - 3000 Hz). This indicates that the virtual plane is appropriate for the surface velocity reconstruction and for the far field sound pressure prediction.