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Coupled vibro-acoustic model updating using frequency response functions

D.V. Nehete, S.V. Modak*, K. Gupta

Department of Mechanical Engineering, Indian Institute of Technology Delhi, Hauz khas, New Delhi 110016, India

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A B S T R A C T

Interior noise in cavities of motorized vehicles is of increasing significance due to the light-weight design of these structures. Accurate coupled vibro-acoustic FE models of such cavities are required so as to allow a reliable design and analysis. It is, however, experienced that the vibro-acoustic predictions using these models do not often correlate acceptably well with the experimental measurements and hence require model updating. Both the structural and the acoustic parameters addressing the stiffness as well as the damping modeling inaccuracies need to be considered simultaneously in the model updating framework in order to obtain an accurate estimate of these parameters. It is also noted that the acoustic absorption properties are generally frequency dependent. This makes use of modal data based methods for updating vibro-acoustic FE models difficult. In view of this, the present paper proposes a method based on vibro-acoustic frequency response functions that allow updating of a coupled FE model by considering simultaneously the parameters associated with both the structural as well as the acoustic model of the cavity. The effectiveness of the proposed method is demonstrated through numerical studies on a 3D rectangular box cavity with a flexible plate. Updating parameters related to the material property, stiffness of joints between the plate and the rectangular cavity and the properties of absorbing surfaces of the acoustic cavity are considered. The robustness of the method under presence of noise is also studied.

1. Introduction

Accurate mathematical models of vibro-acoustic systems are needed to predict vibro-acoustic response accurately. Cavities encountered in aerospace, automotive and other transportation equipment are some of the examples of such systems where forces generated during operation excite the structure causing acoustic response inside the cavity. It is often seen that the acoustic response predicted by the coupled FE model does not correlate well with the measured acoustic response. This situation in structural dynamics for the problem of predicting vibration response is addressed through updating of the FE model (Mottershead and Friswell [1]). Model updating is now considered an acceptable methodology to improve the correlation between the FE model and experimental tests data through adjustment of model parameters that are likely to be in error. Model updating has been extensively studied and various methods have been developed. For vibro-acoustic systems also, model updating techniques can be extended with the objective of improving correlation with the vibro-acoustic test data by adjusting the parameters of the coupled FE model.

* Corresponding author. Tel.: +91 11 26596336; fax: +91 11 26582053.
E-mail address: svmodak@mech.iitd.ac.in (S.V. Modak).

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Decouvreur et al. [2] proposed a method for updating 2D acoustic models using constitutive relation error. Parameters of the acoustic absorption on the interior surfaces of the cavity are updated. The method is later extended to updating of 3D acoustic models with application to a vehicle cabin (Decouvreur et al. [3]). Schedlinski et al. [4] considered updating of damping parameters of the structural model and the acoustic absorption parameters of the acoustic model. The structural damping parameters of the model are updated based on the frequency response functions measured on the structure while the acoustic parameters are updated using the acoustic frequency response measured using a volume velocity excitation source. The procedure was applied on a car cavity. Dhandole and Modak [5] developed a method for updating of acoustic FE models using measured acoustic pressure response. They further report updating of a weakly coupled structural model of a cavity and study its effect on the accuracy of the predicted vibro-acoustic frequency response (Dhandole and Modak [6]). A method for structural FE model updating incorporating two-way vibro-acoustic coupling has been recently developed Nehete et al. [7]. This method extends inverse eigen-sensitivity approach to update undamped structural FE models of cavities by incorporating vibro-acoustic coupling. The method, however, cannot be used for updating of damped models. It is noted that in a damped case, the damping can originate from both the structural as well as the acoustic domains of the cavity. Wan et al. [8] presented a method for acoustic FE model updating by linearizing the relationship between the acoustic FRFs and the acoustic absorption parameters. Modak [9] developed a formulation for direct updating of mass and stiffness matrices of the acoustic and structural domains of a coupled vibro-acoustic model. The method, however, does not take damping of the two domains into account.

It is observed that a vibro-acoustic FE model may have modeling inaccuracies in both the acoustic as well as its structural model. While some of the developed methods address updating of only acoustic models, some other either consider updating of only the structural model or do not consider updating of all possible modeling inaccuracies like related to the stiffness and the damping. A couple of other methods consider updating of undamped coupled models and hence cannot be used for updating damping matrices. The present paper proposes a method for updating of coupled vibro-acoustic FE models considering simultaneous updating of all the parameters and therefore allows updating of the mass, stiffness as well as damping matrices of both the structural and the acoustic domains. The proposed method offers a framework where the modeling inaccuracies of both the models can be addressed while incorporating the two-way coupling. A numerical study of a 3D rectangular cavity with a flexible plate is presented to validate the method.

2. Coupled vibro-acoustic FE model updating

In this section, a method for updating of coupled vibro-acoustic models based on frequency response functions measured on the cavity is proposed. The updating approach is based on posing the problem as a constrained minimization problem so that it could readily be solved using a standard optimization routine. The coupled updating formulation allows taking into account acoustic loading on the structure in the updating process. The method utilizes frequency response functions rather than the modal data and hence allows identification of the frequency dependent absorption properties as well along with the structural updating parameters.

Consider a coupled cavity with volume V. The boundary surface S of the cavity is composed of surface $S1$ that is acoustically hard, surface $S2$ that represents the common boundary between the acoustic domain and the structure and surface $S3$ that is covered with sound absorbing material. The subscripts s and a are used to indicate the structural and acoustic domains respectively. In the following, symbols in bold and upper case represent matrices, those in bold and lower case represent vectors while those in lower case are scalars.

Assuming the acoustic pressure fluctuations inside the cavity to be harmonic with frequency ω rad/s, the homogeneous Helmholtz equation, which is the governing differential equation, is given by,

$$\nabla^2 p + \frac{\omega^2}{c^2} p = 0 \tag{1}$$

The boundary condition over $S1$ will be,

$$\frac{\partial p}{\partial n} = 0 \tag{2}$$

The boundary condition over $S3$ (surface with sound absorbing material having specific acoustic admittance A) will be,

$$\frac{\partial p}{\partial n} = -\rho \cdot j\omega \cdot p.\, A \tag{3}$$

The admittance A is generally complex and is seen to be frequency dependent. In view of this, two models for the acoustic absorption coefficient are assumed. A frequency independent model given by,

$$A = A_1 + jA_2 \tag{4}$$

and a frequency dependent model given by,

$$A\omega = A\omega 1 + j\omega A\omega 2 \tag{5}$$