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ScienceDirect
Applied Acoustics 68 (2007) 739–751
applied acoustics
www.elsevier.com/locate/apacoust

Vibro-acoustic analysis of a rectangular-like cavity with a tilted wall

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Received 30 March 2006; received in revised form 6 April 2006; accepted 11 April 2006
Available online 12 June 2006

Abstract

In this paper, a fully coupled vibro-acoustic model is developed to characterize the structural and acoustic coupling of a flexible panel backed by a rectangular-like cavity with a slight geometrical distortion, which is introduced through a tilted wall. The combined integro-modal approach is used to handle the acoustic pressure inside the irregular-shaped cavity. Based on the model proposed, the distortion effect on the vibro-acoustic behavior of the coupled system is investigated using the averaged sound pressure level inside the enclosure and the averaged quadratic velocity of the vibrating plate. Simulations are conducted to examine the distortion effect on acoustic natural frequencies, acoustic pressures and structural responses. Effects of the wall inclination on coupling coefficients are also assessed, and an index is proposed to quantify the degree of variation of coupling strength.

Keywords: Vibro-acoustic analysis; Coupling; Rectangular-like cavity; Tilted wall

1. Introduction

The noise radiated by a vibrating structure into an enclosed cavity is of particular interest for many industrial applications. Typical examples include cabin noise inside vehicles and aircraft fuselages, which are usually modeled by a cavity enclosed by a flexible

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0003-682X/$ - see front matter
doi:10.1016/j.apacoust.2006.04.005

vibrating structure. The coupled structural vibration and acoustic field form a so-called vibro-acoustic system. Vibro-acoustic analyses of these systems have been extensively carried out using various analytical and experimental methods in the past. Early researches in this field were presented by Junger and Feit [1] and Dowell *et al.* [2,3], who developed a comprehensive modal-based theoretical framework for interior sound field prediction. Since then, a large amount of efforts has been devoted to investigating the vibro-acoustic behavior of such systems, such as analysis of structural–acoustic modal interaction [4–7] and sound radiation prediction [8–11].

In general, structural vibration radiates sound into the enclosure through its coupling with acoustic modes. Therefore, an accurate characterization of the sound–structural interaction is essential for the prediction of acoustic field. Since conventional modal-based methods heavily rely on the availability of the acoustic modes, which are not analytically known in the presence of geometry irregularity, most of previous investigations focused on systems with perfect geometry and homogeneous structural properties [7–10]. In practice, imperfections (geometrical distortion or structural parameter uncertainty) always exist to a certain extent, which may lead to significant discrepancy from results obtained using idealized models, in terms of both eigen-frequencies and responses of the system. In most cases, this problem is not critical since the induced discrepancy is usually gentle and small so that numerical simulations using perfect system can still be applicable to some extent. However, there are circumstances under which the discrepancy becomes very subtle and large. One indication is that in some vibro-acoustic systems, numerical results cannot match the experimental ones [12].

Some techniques and methods have been developed so far to address the increasing interest in the distortion effect on sound–structure interactions [13,14]. Using the acousto-elastic theory, acoustic modal properties of irregular-shaped cavities were computed by approximating the cavity geometry with a set of rectangular subcavities [15]. Based on the Green theorem, Succi calculated the interior acoustic field in an automobile cabin, and the effects of arbitrary shape on the eigenvalues of the system were investigated [16]. In our previous work, a "combined integro-modal approach" was proposed to predict acoustic properties of irregular-shaped cavities [17]. The development of these techniques makes it possible to handle the cavities with irregular shapes in a semi-analytical way. All aforementioned works, however, mainly focused on the prediction of the natural frequencies of cavities and seldom addressed the coupling issue and the possible effects of the geometrical irregularity on system responses. A first attempt was made by extending the combined integro-modal approach to analyze the coupling characteristics between a vibrating panel and an irregular-shaped cavity with a tilted wall [18]. Using the coupling coefficients, effects on the coupling between acoustic modes and structural modes were examined, and it was found that the geometric distortion may dramatically change the coupling nature to thwart the prediction using perfect model. Again, no attention was paid to the effect of wall inclination on the vibro-acoustic behavior of the whole system.

This paper is a continuation of that work [18] and attempts to provide some answers to this problem. A model is first developed to handle the full vibro-acoustic coupling of a vibrating plate backed by an acoustically hard-walled enclosure with a tilted wall, which is introduced to represent the geometrical distortion. The averaged sound pressure level inside the enclosure and the averaged quadratic velocity of the panel are used, respectively, to examine the distortion effect on the acoustic field inside the enclosure and the vibration of