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The use of an active controlled enclosure to attenuate sound radiation from a heavy radiator

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ABSTRACT

Active structural acoustical control usually experiences difficulty in the control of heavy sources or sources where direct applications of control forces are not practical. To overcome this difficulty, an active controlled enclosure, which forms a cavity with both flexible and open boundary, is employed. This configuration permits indirect implementation of active control in which the control inputs can be applied to subsidiary structures other than the sources. To determine the control effectiveness of the configuration, the vibro-acoustic behavior of the system, which consists of a top plate with an open, a sound cavity and a source panel, is investigated in this paper. A complete mathematical model of the system is formulated involving modified Fourier series formulations and the governing equations are solved using the Rayleigh-Ritz method. The coupling mechanisms of a partly opened cavity and a plate are analysed in terms of modal responses and directivity patterns. Furthermore, to attenuate sound power radiated from both the top panel and the open, two strategies are studied: minimizing the total radiated power and the cancellation of volume velocity. Moreover, three control configurations are compared, using a point force on the control panel (structural control), using a sound source in the cavity (acoustical control) and applying hybrid structural-acoustical control. In addition, the effects of boundary condition of the control panel on the sound radiation and control performance are discussed.

1. Introduction

Active structural acoustic control (ASAC) and active noise control (ANC) are two techniques capable to attenuate sound radiation from vibrating structures. Comparing with ANC which utilizes sound to offset noise, ASAC devotes to reduce noise by modifying the vibration output of sources. Especially for thin structures, the potential of using control force(s) to attenuate sound radiated from [1–6] or sound transmission through [7–9] thin structures have been widely investigated. However, for heavy vibrators, such as power plants or transformers, it is difficult and inefficient to apply control force directly to those radiators. Specifically, a large number of control forces and great force amplitudes are generally required. As for ANC, although directional or global sound reduction could be obtained, the number and the size of loudspeakers are always concerned which limit the application of ANC for large radiating surface at low frequency range [10,11].

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To address this issue, secondary structures which cover the sources have been employed for the purpose of insulating sound. In addition, these structures provide indirect paths to active control. For a panel radiator, the configuration of plate-cavity-plate has been intensively studied and great sound transmission losses could be guaranteed [12–14]. Another configuration presented by Pan et al. [15] employing a plate with an open instead of an entire plate. By adjusting the control force acting on the secondary plate, an inefficient out-of-phase dipole pattern could be formed involving the motion of the plate and the motion of the air in the open. It is reported that, the sound pressure level at different reference points after control were greatly reduced. Burgemeister [16] expanded the work done by Pan et al.[15] and studied the use of multi-hole perforated panel on the active control of sound radiation from a plate both theoretically and experimentally. In an attempt to explain the large discrepancy between the theoretical and experimental results, he worked out that the assumption of uniform pressure in the cavity did not appear to be valid. Then, an assumption of no coupling between sound fields and plates has been made to evaluate the maximum of active noise attenuation. The main focus of this paper are to complete the theoretical model by describing the motion of the plate, sound pressure inside the cavity and their interaction more precisely and further investigate the control potential of the configuration presented by Pan [15].

There is a lot of researches could be found providing insights about the coupling between structure and cavity. Generally, the coupling patterns between a finite sound field and flexible structures enclosed are classified as structure or cavity controlled modes. Especially, for the model of a rectangular cavity with a simply supported plate, the modal solutions reveal that the modal couplings are selective [17–19]. However, there is no universal model for a partly opened sound cavity. Various treatments were presented dealing with the open interfaces and limitations of these methods were reported. Furue [20] considered the sound propagation from a cavity into external field through an open. In his study, integral equation method and Kirchhoff's diffraction theory were employed for low and high frequency ranges, respectively. Pàmies [21] formulated a rigid sound cavity with one open using modal expansion approach based on Green's function method. In that paper, the contribution of the open to the acoustic response was described by specific acoustical modal admittances. Other numerical methods could be found dealing with the open using boundary element method (BEM) or BEM and finite element method (FEM) [22,23]. Considering a sound field with both flexible and open boundary, Kim et al. [24] investigated the acoustic behavior of a sound cavity which was partly covered by a plate experimentally. The visualization of sound fields inside and outside identified the main paths of sound radiation. Their further analysis [25,26] introduced Kirchhoff-Helmholtz integral and Green's function to derive modal solutions for a 2D cavity which was partly covered by an infinite flexible plate. Yu et al. [27,28] formulated the sound pressure inside an open by a series expansion for x&y directions and Taylor's first order expansion for z direction.

In this paper, the air in the open is regarded as a thin mass layer. Accordingly, the air layer's motion can be formulated in the same way as a plate's motion. By establishing Lagrangian equations of the coupled system and employing Rayleigh-Ritz method, the system responses can be obtained. Based on the modal analysis, the potential of applying active control to the subsidiary structure for attenuating sound radiation from the primary heavy source is discussed. Control performances of two strategies, minimization the total sound radiation power and the cancellation of volume velocity, on the total radiated power are examined. Besides, the added enclosure not only permit ASAC on the thin plate, but also provide a sound field which is suitable for applying ANC through mounting speakers on the sidewall. Correspondingly, three different control configurations of structural, acoustic and hybrid control are employed and the control performance, effectiveness and economy have been discussed.

2. Theoretical model descriptions

As shown in Fig. 1, the theoretical model is constructed by a bottom plate, a plate placed in front of it with a rectangular cut-out and four rigid walls enclosed. Here, the bottom plate represents a primary heavy vibrator while the top plate and cavity are secondary control structures. The size of the two plates is $L_x \times L_y$ and the distance between the two plates is L_z. The thickness of the control plate is h_{cp}. With a dimension of $a \times b$, an open is located at (h_x, h_y) of the control panel. Moreover, the boundaries of the control plate are constrained by transverse and rotational springs for which arbitrary boundary

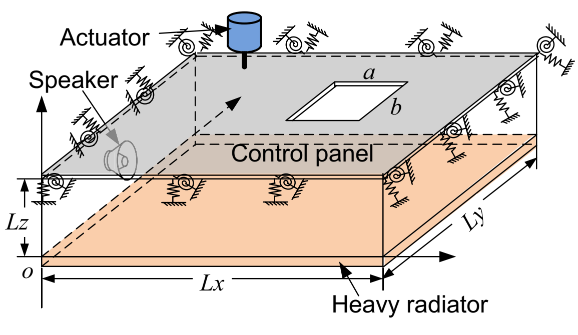

Fig. 1. Sketch of the radiator& control enclosure model.

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