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Signal response of rib-stiffened plates covered by decoupling coating layers

F.X. Xin [a,b]

[a] State Key Laboratory for Mechanical Strength and Vibration, School of Aerospace, Xi'an Jiaotong University, Xi'an 710049, People's Republic of China
[b] School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA

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ABSTRACT

This paper proposes a fully elastic theoretical model for the signal response of a periodically rib-stiffened plate covered with a decoupling coating layer, in which the elastic plate and the coating layer are modeled by adopting the plain strain elasticity theory. The fluid loadings on the two sides of the structure are taken into account, which thus enables the model to handle the case that the coated structure is immersed in two different fluids. The periodicity introduced by the parallel distribution of rib-stiffeners is considered by utilizing the space harmonic series to express the solutions. The resultant equations are formulated by the displacement and stress continuity conditions at the fluid/coating, coating/plate and plate/fluid interfaces. The signal response of the structure can be obtained by solving these resultant equations, built upon which numerical investigation is conducted. Specific interests are focused on the investigation for the signal velocity component distributions with the sound incident angle, frequency, location through the coating thickness, as well as the effect of coating material properties. The drawn conclusions provide useful guidance for the vector velocity measurement and optimal design of the rib-stiffened plate covered with the decoupling coating layer.

1. Introduction

The characterization of vibration and acoustic response of coated structures is driven by the need to understand and improve the performances for passive noise control of the attached decoupling coating layer [1]. Commonly, the coated structures are comprised of an elastic structure and decoupling coating layer that possesses relatively low stiffness in comparison to the elastic structure. Therefore, the coating layer is able to sustain the dynamic pressure in the neighboring fluid in the way of thickness deformation. The deformation creates a pressure-released boundary, or in other words, gives rise to the decoupling of motions of the elastic structure and of the fluid in contact with the decoupling coating layer [2].

As a foundation of the investigation for the coated structures, early works have primarily focused on the sound radiation, reflection and transmission properties of elastic structures [3–9]. For instance, Fiorito et al. [3] analyzed the sound transmission and reflection characteristics of an elastic layer immersed in a fluid in terms of the developed resonance formalism. Jackins and Gaunaurd [4] formulated a resonance scattering theory to study the acoustic reflection from a stack of arbitrarily many elastic flat plates. Adopting the two-dimensional plain strain elasticity theory, Chonan and Kugo [5]

E-mail addresses: fengxian.xin@gmail.com, fxxin@seas.harvard.edu

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established a theoretical model for the transmission performances of a three-layered infinite plate excited by a plane acoustic wave. Also, the sound reflection and transmission properties of anisotropic laminates submerged in fluids were theoretically investigated by Cai et al. [10].

Actually, numerous efforts have been dedicated to the investigation for the vibroacoustic behavior of elastic plates covered with decoupling coating layers. Among these, the locally reacting model was often applied to study the sound radiation performance of the structure coated with a decoupling layer, which assumed the coating layer behaving as evenly distributed massless springs on the plate [11]. Using the locally reacting model, Crighton [12] studies the sound reflection from an infinite elastic panel coated with a decoupling layer under fluid loading. As an extension, Maidanik [13] further investigated the acoustic behavior of multilayered infinite panels immersed in fluid media. Considering a finite case, Foin et al. [2] theoretically investigated the vibroacoustic behavior of a simply supported rectangular plate covered by a locally reacting decoupling layer.

In view that only the transverse strain of the coating layer can be described by the locally reacting model, such model is inherently incapable of capture the accurate wave propagation in the coating layer. To address this defect, the elasticity theory that is able to account for the dilatational wave and shear wave propagations in solid layers has now often employed to model the dynamic response of the layers. On the basis of the theory of elasticity, Ko [14] developed a theoretical model to evaluate the noise reduction of a vibrating plate covered with an elastomeric baffle layer. Concentrated on the signal velocity response, Keltie [15] analytically addressed the issue that a compliant elastic coating attached to a submerged thin plate under sound pressure excitation. Combining the elasticity theory and the thin plate theory, respectively accounting for the coating layer and plate layer, this kinds of theoretical models [2,11,15,16] also could give enough accurate predictions for the vibroacoustic behavior of coated plates. Recently, a fully three-dimensional analytical model is proposed by Hull and Welch [17] to examine the elastic response of a fluid-loaded acoustic coating affixed to a rib-stiffened plate, which well solves this three-dimensional problem.

However, pervious works commonly paid attention to the sound radiation or transmission behaviors of flat coated plates. To the best knowledge of the author, only a few papers [17,18] have taken the periodically rib-stiffeners into account. Since Hull and Welch's work mainly focused on three specific model results, there yet lacks detailed analyses for the signal velocity response of periodically rib-stiffened plates covered with decoupling coating layers to date. As a vector velocity response inherently contains much more information than a scalar pressure output, the signal velocity response of the coated rib-stiffened plates is of particular concern. To address this deficiency, as an extension of but different from Hull and Welch's work [17], this paper presents a fully elastic theoretical model for the signal response of a periodically rib-stiffened plate covered with a decoupling coating layer, in which the elastic plate and the coating layer are modeled by adopting the plain strain elasticity theory and the fluid loadings on both sides of the structure are taken into account. The present work gives detailed analyses with fundamental insights into the influences of sound incident angle, location through the coating thickness and coating material properties on the signal velocity responses of the structure. Also, the waveguide behaviors of the coating layer are elucidated with closed-form equations derived and important conclusions deduced.

2. Theoretical model

2.1. Fluid–structure coupling responses

A schematic illustration of the considered structure is shown in Fig. 1, which consists of a periodically rib-stiffened plate covered by a decoupling coating layer. The structure is immersed in two different fluid media, which are both assumed to be ideal, inviscid acoustic fluid media. The structure has infinite spatial extent in the x- and z-directions, also with the rib-stiffeners infinite extended in the z-direction. The elastic plate and the decoupling coating layer are both considered as linear, homogeneous and isotropic elastic material, respectively with the thickness of h_b and h_t. The rib-stiffeners on the elastic plate are equally spaced at a distance of L in the x direction, with h_r and t being the height and thickness, respectively. The decoupling coating layer and rib-stiffeners are all perfectly bonded on the elastic plate. Considering the system to be a two-dimensional plane strain problem, a time-harmonic plane acoustic wave is assumed to incident on the decoupling coating layer at an angel θ (with respect to the y axis) from the upper fluid medium, which has two wavenumber components k_x and k_y in the x- and y-direction, respectively.

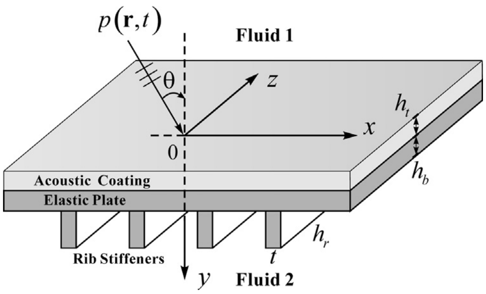

Fig. 1. Schematic illustration of the signal response of a rib-stiffened plate covered by a decoupling coating layer immersed in two fluids.