Journal of Sound and Vibration 426 (2018) 244–257

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Optimization of decoupling performance of underwater acoustic coating with cavities via equivalent fluid model

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ARTICLE INFO

Article history:
Received 24 July 2017
Received in revised form 13 April 2018
Accepted 16 April 2018

Handling Editor: L. G. Tham

Keywords:
Acoustic coating
Decoupling
Underwater sound radiation
Equivalent fluid model

ABSTRACT

Acoustic coatings with periodically arranged internal cavities have been successfully applied in submarines for the purpose of decoupling water from vibration of underwater structures, and thus reducing underwater sound radiation. Previous publications on decoupling acoustic coatings with cavities are mainly focused on the case of coatings with specific shaped cavities, including cylindrical and conical cavities. To explore better decoupling performance, an optimal design of acoustic coating with complex shaped cavities is attempted in this paper. An equivalent fluid model is proposed to characterize coatings with general axisymmetrical cavities. By employing the equivalent fluid model, an analytical vibroacoustic model is further developed for the prediction of sound radiation from an infinite plate covered with an equivalent fluid layer (as a replacement of original coating) and immersed in water. Numerical examples are provided to verify the equivalent fluid model. Based on a combining use of the analytical vibroacoustic model and a differential evolution algorithm, optimal designs for acoustic coatings with cavities are conducted. Numerical results demonstrate that the decoupling performance of acoustic coating can be significantly improved by employing special axisymmetrical cavities as compared to traditional cylindrical cavities.

1. Introduction

Attaching a layer of acoustic coating to an underwater structure is a well-known technique to reduce sound radiation from the structure. An acoustic coating is usually made of acoustically soft material which can decouple the water from vibration of the base structure. In addition, the decoupling capability of an acoustic coating can be further enhanced by introducing cavities into the coating.

Many efforts have been exerted to analyze the vibration and acoustic characteristics of underwater structures covered with acoustic coatings. Sandman [1] developed a vibroacoustic model of a three-layered finite plate with fluid loading. It was shown that core stiffness and damping are primary factors in the control of resonant vibration response and sound radiation. It was also revealed that the cross-modal coupling effect can be neglected for sound radiation prediction when considerable core damping is in presence. Ko [2] evaluated the reduction of structure-borne noise of an underwater, infinite plate with an elastomer coating. It was shown that the amount of noise reduction increases as the coating layer thickness increases and the

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https://doi.org/10.1016/j.jsv.2018.04.024

loss factor associated with the longitudinal wave increases, but decreases as the coating density increases and the longitudinal wave speed increases. It was also found that the shear wave speed in the coating and the loss factor associated with the shear wave have negligible effect on the noise reduction performance. Berry, Foin and Szabo [3,4] investigated the vibroacoustic response of a simply supported rectangular plate covered by an acoustic coating and immersed in water. Their research showed that shear waves in the acoustic coating usually have little influence on the sound radiation in water, as compared to longitudinal waves. Wang et al. [5] presented an analytical model for the prediction of vibration and sound radiation of an underwater, finite stiffened plate that is covered with an acoustic coating and subjected to a point force excitation. Their theoretical predictions were compared with experimental results, from which a good agreement was observed.

The investigations mentioned above are mainly focused on homogeneous acoustic coatings, while in recent years more attention is paid to the case of inhomogeneous coatings to explore better acoustic performance. Tao et al. [6] presented an analytical model to predict the underwater noise reduction performance of a void acoustic coating covered on an infinite plate under point force excitation. Their studies showed that the primary mechanism of the noise reduction is the vibration isolation between the two surfaces of the coating layer, rather than the plate vibration reduction. Zhu et al. [7] presented numerical and experimental investigations on the underwater noise reduction capabilities of various acoustic coatings attached to a stiffened metal box. They found that the chiral acoustic coating filled with expanded polystyrene foams has a better performance of noise reduction than solid coating and chiral coating without fillings. Zhang and Pan [8,9] studied the effect of attached or embedded signal conditioning plates on the underwater sound radiation of an infinite plate structure with acoustic coating. Their research showed that the signal conditioning plates may change the vibration and radiated sound by scattering and reflecting structural waves in the acoustic coating. Huang et al. [10] investigated the underwater decoupling properties of an acoustic metamaterial coating with embedded locally resonant structures. It was shown that such acoustic metamaterial coating exhibits significant noise reduction performance around the resonance frequency of locally resonant structures.

Although many previous work have been carried out to examine the vibroacoustic characteristics of various acoustic coatings, little has been conducted to perform optimal design of acoustic coatings with internal structures for improving decoupling capabilities. The motivation for this study is to provide an optimal design of decoupling acoustic coatings with internal cavities, which represent the most common type of internal structures used in practical decoupling coatings. Such an optimal design implies that complex shaped cavities should be considered for the construction of decoupling acoustic coatings. However, a problem then arises in how to efficiently predict the decoupling properties of an acoustic coating with complex shaped cavities. On the one hand, it is difficult to develop analytical methods to treat coatings with complex shaped cavities. On the other hand, numerical methods such as finite element (FE) method may be employed, but a very large sized computational model is required for a detailed description of a large number of complex cavities, which inevitably results in low calculation efficiency. To address the problem in this paper, an equivalent fluid model is provided to characterize acoustic coatings with arbitrarily shaped axisymmetrical cavities. By using the equivalent fluid model, the decoupling performance of acoustic coatings with axisymmetrical cavities can be predicted accurately and efficiently, which greatly facilitates the optimal design of this work.

2. Equivalent fluid model

The general physical system considered in this work is an infinite plate covered with a layer of acoustic coating embedded with axisymmetrical cavities (the axis of symmetry is perpendicular to the surface of the base plate) and immersed in water, as shown in Fig. 1(a). The cavities are periodically distributed with a two-dimensional square lattice along the *x*-*y* plane. The lower surface of the base plate is in contact with vacuum, while the upper surface of the coating layer is in contact with water. It is assumed that the base plate is excited by a time-harmonic line force. As a result, the coating layer vibrates together with the base plate and radiates sound into the water. The thickness of the base plate and the coating layer are h_1 and h_2, respectively.

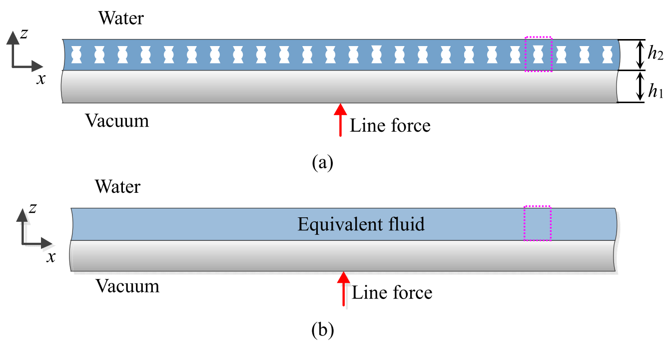

Fig. 1. An infinite plate covered with a layer of acoustic coating embedded with periodic cavities: (a) original system, (b) equivalent system.