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Analysis of different techniques to improve sound transmission loss in cylindrical shells

Pouria Oliazadeh, Anooshiravan Farshidianfar *

Department of Mechanical Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

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ABSTRACT

In this study, sound transmission through double- and triple-walled shells is investigated. The structure-acoustic equations based on Donnell's shell theory are presented and transmission losses calculated by this approach are compared with the transmission losses obtained according to Love's theory. An experimental set-up is also constructed to compare natural frequencies obtained from Donnell and Love's theories with experimental results in the high frequency region. Both comparisons show that Donnell's theory predicts the sound transmission characteristics and vibrational behavior better than Love's theory in the high frequency region. The transmission losses of the double- and triple-walled construction are then presented for various radii and thicknesses. Then the effects of air gap size as an important design parameter are studied. Sound transmission characteristics through a circular cylindrical shell are also computed along with consideration of the effects of material damping. Modest absorption is shown to greatly reduce the sound transmission at ring frequency and coincidence frequency. Also the effects of five common gases that are used for filling the gap are investigated.

1. Introduction

Similar to beams and plates, thin cylindrical shells are the practical elements of various engineering structures such as pipes and ducts, car bodies, space shuttles, aircraft fuselages, ship hulls and submarines. Making a thin cylindrical structure with double – or triple – walled shells has turned them into more effective sound barriers and more useful especially in practical aeronautical applications. However, analyzing the sound characteristics of thin cylindrical shells is highly complicated. This situation occurs mainly because the equations of motion in a thin cylindrical shell and the mathematical calculations are really cumbersome because of the presence of structure – acoustic coupling effects.

Noise transmission through a thin cylindrical shell was studied by many researchers including Crocker [1], Koval [2–4], Jha et al. [5,6], Bullmore et al. [7], Blaise et al. [8], Ruotolo [9,10] and Daneshjou [11] for study and design of aircraft.

Eliminating the vibration of a thin circular cylindrical shell and its interior acoustic pressure has become an important research topic recently. Narayanan et al. [12] showed that sandwich shells with applied damping treatment have better noise transmission characteristics in the higher frequency range. Lee et al. [13–15] investigated the structural response of single – and double – walled thin shells and stiffened structures. They investigated important design parameters such as radius, thickness, stiffener mass, stiffener spacing and stiffness of the stiffener. Jeong et al. [16] studied the acoustic

* Corresponding author.
E-mail address: farshid@um.ac.ir (A. Farshidianfar).

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transmission characteristics in a cylindrical cavity system at resonance frequencies. Zhou et al. [17,18] studied sound transmission through a system of double – walled panels and double thin shells, lined with poroelastic materials in the presence of external mean flow. Later on, Liu and He [19] addressed sound transmission through double-walled cylindrical shells that are lined with poroelastic materials and added the effect of external mean flow and then compared their results with those presented in Zhou's paper. Magniez et al. [20] used first-order shear deformation and three-dimensional elasticity theories to calculate sound transmission loss in an infinite multilayered cylinder composed of orthotropic skins and an isotropic polymer core. Xin and Lu [21] calculated sound transmission loss of a triple – panel partition and developed an analytical model for sound transmission through it. Liu [22] calculated transmission loss of a triple – panel structure lined with poroelastic materials and studied the effects of air gap flow on acoustic transmission through a double – wall sandwich panel [23] and a double – wall sandwich shell [24] lined with poroelastic materials. The research works presented so far [13–15,17–24] do not analyze the effect of triple – walled shells on reducing noise transmission. Also the effect of air gap size has not been mentioned in double – and triple – walled cylindrical shells. Moreover, very few studies that have investigated the effects of material damping [25,26] on sound transmission through thin cylindrical shells have been reported. Besides air, there are other gases that can be used to fill the shell's gap. Even in these few studies, nearly none have taken into account the effect of various gases.

In the present study, an exact analytical approach is discussed to investigate the acoustic behavior of double – and triple – walled thin cylindrical shells and find sound transmission losses (TL) based on Donnell's theory. Oliazadeh et al. [27,28] showed that Donnell's theory [29] is precise when used to study the vibration of cylindrical shells. In order to assure that Donnell's theory is still precise and reliable in analyzing noise and acoustics of thin cylindrical shells, the authors check the accuracy of this theory in the high frequency region by comparing the natural frequencies obtained using Donnell's theory with experimental results. Donnell's theory is also compared with Love's theory [18] and it is shown that Donnell's theory is more accurate than Love's theory and it predicts the transmission loss trend better than Love's theory in the resonance – control region. Then, the results and discussions for transmission loss of double – and triple –walled shells with varying air gap sizes are presented and the effects of five common gases, namely Argon, Neon, Oxygen, Helium and hydrogen used for filling the gap are investigated. It is shown that using double – or triple – walled shells along with filling the air gaps with some proposed suitable gases and without any increase in the total thickness of the shell compared to the single – walled shell is an applicable technique in order to isolate the sound transmission and restrict it in the cylindrical shell.

2. The governing equations

2.1. Wave equations

The cylindrical shell considered in the analysis consists of an infinitely long thin circular shell to which an oblique plane wave with an incidence angle of γ is incident as shown in Fig. 1. The shell is characterized by its radius R_s, constant wall thickness h_s, Poisson ratio υ_s, *in vacuo* bulk mass density ρ_s and *in vacuo* bulk Young's modulus E_s. For a double- or triple-walled shell, these quantities are represented by R_{si}, h_{si}, υ_{si}, ρ_{si} and E_{si}; where $i = \begin{cases} 1,2 & \text{for double walled shell} \\ 1,2,3 & \text{for tripple walled shell} \end{cases}$.
Fig. 2 shows which number correspond to which layer of the shell.

Here the wave equations and the equations of motion of the shell are presented for triple- walled shells. They can be obtained in a similar manner for the double-walled shells. However, sound transmission losses will be presented for both

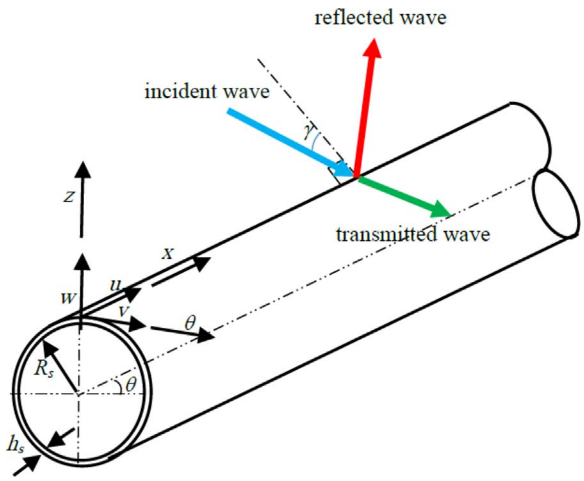

Fig. 1. Thin circular cylindrical shell: coordinate system and dimensions.

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