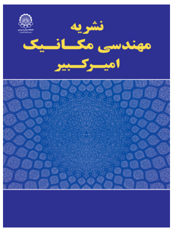

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Sound Transmission Loss of Truncated Conical Shells with Porous Materials

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ABSTRACT: A theoretical model is proposed to study the sound transmission loss of a truncated conical shell with a porous layer. The isotropic thin-walled conical shell is excited by an oblique incident plane sound wave, which impinges on the outer surface of the shell. The governing equations of the shell motion are obtained by Love's theory, and a convergent power series solution is applied to obtain the exact displacements of the shell. An equivalent fluid model based on Biot's theory is considered to describe the wave propagation in the porous material. The model results are firstly validated against the results of prior studies. Then, the effects of several design parameters such as different boundary conditions at the ends of the shell, cone angle, incident sound wave angle and material properties of the shell are studied on the characteristics of the sound transmission loss. The proposed model can provide an effective tool in the acoustic design stage of the truncated conical shells. In addition, the transmission loss is obtained in the presence of the porous layer with two different configurations. The results generally show the desirable performance of the porous layer in the sound insulation ability.

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1- INTRODUCTION

Plate and shell structures are widely used in different types of industries such as aerospace, automotive and marine. However, the interaction of these structures and surrounding fluids is a crucial issue. Because it can induce transmission of undesirable vibroacoustic energy into systems, and consequently, it can cause noise pollution, structural fatigue and a disturbance to the electrical equipment.

Thin elastic structures lined with elastic porous materials are commonly found in the body of different types of vehicles like airplanes, cars, and trains. Because using the porous materials is an effective passive control and inexpensive method to considerably improve the acoustic insulation properties of a system without any significant increase in its weight. Therefore, they have attracted extensive research attention for decades.

The sound transmission through plates and cylindrical shells has been studied by several researchers such as Beranek and Work [1], Smith [2], Bolton et al. [3], Lee and Kim [4], Xin and Lu [5], Zhou et al. [6], Oliazadeh et al. [7], Golzari and Jafari [8]. Bolton et al. [3] analytically and experimentally investigated the sound transmission loss of multi-panel structures with poroelastic lining. Xin and Lu [5] performed both theoretical and experimental studies on the vibroacoustic performance of a rectangular double-panel partition with the clamped boundary conditions. Zhou et al. [6] analytically calculated the transmission loss of an infinite double-walled sandwich cylindrical shell. Oliazadeh et al. [7] experimentally and theoretically studied the sound transmission into cylindrical shells. The acoustic insulation performance of triple- and multi-walled sandwich cylindrical shells with poroelastic cores were investigated by Golzari and Jafari [8].

However, sound transmission through truncated conical shells has rarely been studied. In this regard, it can only be referred to the experimental work of Vipperman et al. [9]. But a theoretical model has not been addressed in the literature. It is mainly because of the increased mathematical complexity of the equations governing the conical shell motion and acoustic media, boundary conditions, solutions and calculations. Therefore, the main purpose of this study is to present an analytical model to investigate the sound transmission behavior of truncated conical shells and the effects of several important parameters including the boundary conditions at the ends, cone angle, incident sound wave angle and material properties of the shell. Moreover, the effect of elastic porous materials on sound reduction is studied.

2- METHODOLOGY

The truncated conical shell with the smaller radius R_1, larger radius R_2, cone angle 2α, wall thickness h, height L and slant height L_s is shown in Fig. 1. The simply supported boundary condition is considered at both ends. The shell is thin, isotropic and homogeneous. A harmonic plane sound wave impinges on the external surface with the incidence angle β with respect to N, and it is partially reflected and partially transmitted into the inner cavity, which is assumed to be anechoic.

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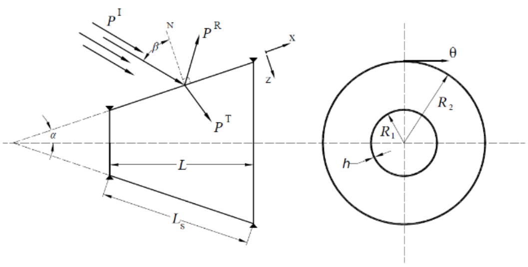

Fig. 1. A schematic sketch of sound transmission through a truncated conical shell

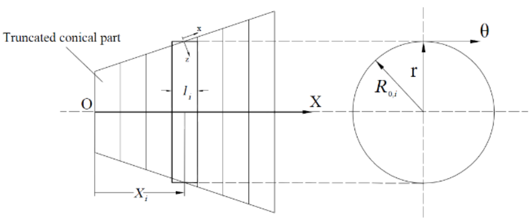

Fig. 2. A schematic sketch of the fluid-conical shell interaction model

By employing Hamilton's principle, the governing equations of the conical shell motion are extracted based on Love's theory [10]. Also, an equivalent fluid model based on Biot's theory [11] is employed for describing the wave propagation into the porous medium. Furthermore, the obtained equations for sound pressures satisfy the homogeneous Helmholtz equation in the acoustic fields [4,6]. Then, by using the governing equations of shell motion and acoustic media, boundary conditions at the interfaces of the shell and acoustic media, and boundary conditions at the ends of the shell, the vibroacoustic problem of the truncated conical shell is implemented.

In order to calculate the exact dynamic response of the shell, a convergence power series solutions is used. Also, to extract the sound pressures acting on the conical shell surfaces, as shown in Fig. 2, the shell is divided into several truncated segments which are narrow enough that the quantity of acoustic pressures on a conical part can be equal to its cylindrical counterpart with the same mean radius and length.

Finally, the sound power transmission coefficient is obtained from the ratio of the transmitted sound power to incident sound power.

3- RESULTS AND DISCUSSION

In Fig. 3, the average transmission loss of the present model is compared with the experimental data of Vipperman et al. [9] who measured the noise reduction of a truncated conical shell in a diffuse sound field. Because, in the experiment, the inner cavity was not anechoic, and also four speakers were used outside the shell to simulate the diffuse sound field, it is expected that the amplitudes of experimental results will be lower than those of the analytical results. Therefore, the main purpose here is a qualitative comparison. In this regard, it is seen that the level of experimental data is lower than that of the analytical results, and a similar tendency between the curves is observed.

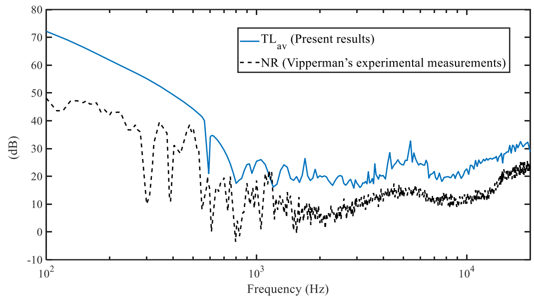

Fig. 3. Comparison of the present results with the experimental results of Vipperman et al. [9]

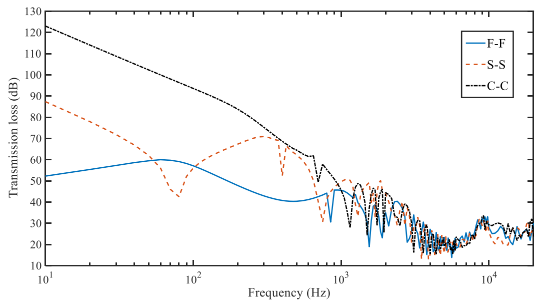

Fig. 4. Effect of the boundary conditions on the sound transmission through a truncated conical shell

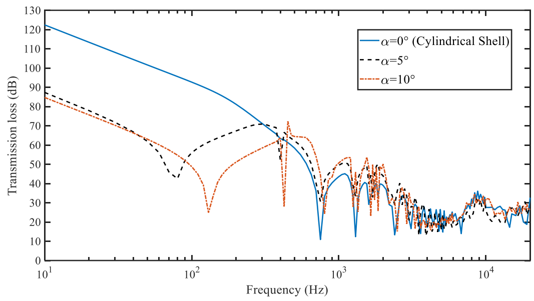

Fig. 5. Effect of the cone vertex angle on the sound transmission through a truncated conical shell

Fig. 4 compares the transmission loss results of the shell at different boundary conditions. It is shown that the effect of boundary constraints is more significant at low frequencies, in which the highest and lowest transmission loss are generally achieved by clamped-clamped (C-C) and free-free (F-F) boundary conditions, respectively.

From Fig. 5, it is seen that the transmission loss reduces at frequencies below 400 Hz as the cone angle is increased, particularly for the cylindrical shell compared with the conical shell. However, increasing the cone angle slightly provides better transmission loss at higher frequencies.

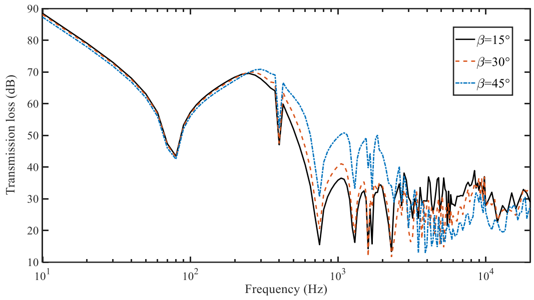

Fig. 6. Effect of the incident sound wave angle on the sound transmission through a truncated conical shell

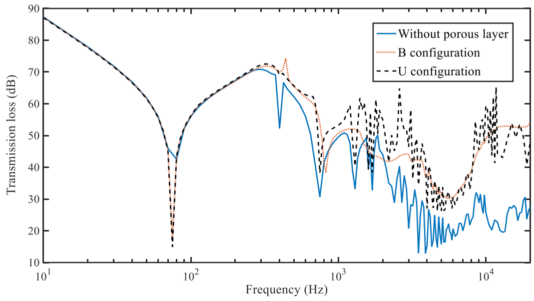

Fig. 7. Effect of the porous material on the sound transmission through a truncated conical shell

Fig. 6 shows that the sound transmission loss significantly decreases in the frequency range of about 250 Hz to 2800 Hz as the incidence angle is reduced. But, a rise in the results is observed at other frequency bands.

Finally, the influence of elastic porous material is discussed in Fig. 7. The B conFiguration represents that the porous layer is directly attached to the shell, while in the U configuration, it is separated by an air gap from the shell. It is observed that the porous layer has negligible effect at low frequencies. However, at high frequencies, it provides better transmission loss. Also, the results suggest that to achieve better sound insulation, the porous layer should be separated from the shell by an air gap.

4- CONCLUSIONS

In this work, an analytical model was presented to study the sound transmission loss of truncated conical shells subjected to a plane acoustic wave. Also, the effects of several design parameters were investigated. The following important results were obtained:

1- The effect of boundary conditions is found to be more significant at low frequencies.

2- The transmission loss reduces in the low frequency range as the cone angle is increased, but it slightly increases in the middle and high-frequency ranges.

3- The transmitted sound power increases at middle frequencies when the incidence angle is decreased, which is opposite to low and high frequencies.

4- Except at low frequencies, Porous materials reduces the transmitted acoustic power in most of the frequency bandwidth. Also, to achieve better transmission loss, the porous layer should be separated from the shell by an air gap.

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