Sound Transmission through Permeable Double-leaf Membranes

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Abstract: This paper studies sound transmission through a double-leaf membrane (DLM) with permeability in its interior leaf. The transmitted sound field through a permeable DLM is analysed theoretically by considering the coupled motion of the membranes and the sound fields. The effect of an absorbent layer in the cavity between the two leaves is also considered by modelling the structure to have a multiple-layered cavity. Numerical examples are shown to illustrate the effects of the parameters of permeable DLMs.

INTRODUCTION

The recent increase in the number of membrane-structure buildings has brought membranes into wide variety of uses as building and acoustic materials. The classical use of membranes has been as conventional membrane-type absorbers(1,2). There have also been some attempts to use membranes for sound reflectors in auditoria(3). The basic membrane-structures in a building of this type have been discussed in our previous papers(4,5). Double-leaf membranes (DLMs) with a permeable interior leaf are one of the typical constructions in membrane-structure buildings. A theory to predict the sound pressure reflected by, and transmitted through, this type of DLM was established by taking into account the coupled motion of the membranes and the surrounding sound field(6). In this same paper the theory was experimentally validated. That work focussed on absorption characteristics since the lack of absorption is one of the main acoustical problems in this type of building. The present paper investigates the sound transmission through a structure of this type in order to gain insight into its sound insulation performance which, in many cases, needs to be improved. The effects of the parameters of the DLM on its transmissibility are demonstrated and discussed through numerical examples. The effect of an absorbent layer in the cavity is also examined.

THEORETICAL ASSUMPTIONS

Consider the infinite DLM in Fig 1. Two infinite membranes are placed parallel to each other with a cavity of depth \( d \) in-between. Leaf 1, on which a plane wave is incident at the angle \( \theta \), has permeability characterised by its flow resistance, \( R \). Leaf 2, which is impermeable, is characterised by its surface acoustic admittance, \( A_3 \) (face) and \( A_4 \) (back). The areal mass and tension of the leaves are \( m_1 \), \( T_1 \) (leaf 1) and \( m_2 \), \( T_2 \) (leaf 2). The cavity is modelled to have three layers each of which can contain different media to generalise the model. The sound wave transmitted through the structure is analysed by coupling Helmholtz integrals for the sound field and equation of membrane motion. Details of the analysis are given in (6,7). All results will be given in field-incidence-averaged values which average the oblique incidence values over the range of 0-78 degree of the angle of incidence.

PARAMETRIC STUDY

Effect of absorbent layer in the cavity: Figure 2 shows the calculated TL of a permeable DLM with an air cavity [1] and that with an absorbent layer in the cavity [2]. In both cases the TL of a permeable DLM shows a similar tendency to that of an impermeable DLM, although the TL of the former is lower. The absorbent layer in the cavity increases the TL mainly at mid-high frequencies. Memorial related parameters: Effect of flow resistance of leaf 1, \( R \), on TL is shown in Fig 3. As \( R \) increases, TL increases mainly at high frequencies: TL curves become steeper to coincide with TL for impermeable case. A dip due to the mass-spring resonance of leaves and cavity appears around 400 Hz in high \( R \) cases [4,5]. Dips due to the
acoustic resonances of the cavity are also seen at high frequencies in [4,5]. All of those dips disappear and the curves become smooth when the cavity is damped with absorbent.

The mass of leaf 1, $m_1$, only affects TL at low frequencies: TL increases slightly at low frequencies with increasing $m_1$, because of the increasing internal energy loss in the leaf(8). The effect of the mass of leaf 2, $m_2$, on TL is more significant: TL drastically rises with increasing $m_2$ at high frequencies. The specific acoustic admittances of leaf 2 surfaces ($A_3$, $A_4$) have only a negligible effect, increasing TL very little.

Cavity related parameters: Unlike the absorptivity of a permeable DLM, which is considerably affected by the cavity depth, the TL shows little change around the resonance dips if the cavity depth changes.

Figure 4 shows the effect of the thickness of the absorbent layer in the cavity on TL. At mid-high frequencies the TL increases dramatically with the increasing thickness of the layer, whereas the effect is small below 125 Hz. In this example the cavity depth is kept constant so that the air gap behind the absorbent layer becomes thinner as the layer thickness increases. When the thickness of the absorbent layer is kept constant, and the depth of the cavity increases, TL only changes slightly, as was observed with cavity depth.

Figure 5 shows the effect of the flow resistance $R_d$ of the absorbent layer. $R_d$ affects TL drastically: A higher $R_d$ results in higher TL. A very high $R_d$, such as in cases [4,5], makes the DLM behave like an impermeable DLM, which is why TL increases considerably even at low frequencies in those cases. Since $R_d$ is a product of flow resistivity $R_f$ and thickness $h$, there are various combinations which give the same $R_d$. However, provided that $R_d$ is kept constant, a thicker material gives a higher TL, even if $R_f$ is lower. It is of some interest where in the cavity to put the absorbent layer. However, the effect of the change in the position of the absorbent layer is only negligible on TL, while it is larger on absorption.

REFERENCES