Journal of Sound and Vibration 410 (2017) 209–216

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

Sound transmission of a spherical sound wave through a finite plate

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ARTICLE INFO

Article history:
Received 28 March 2017
Received in revised form 3 August 2017
Accepted 16 August 2017

Handling Editor: L. G. Tham

Keywords:
Sound transmission loss
Vibro-acoustics
Plate vibration

ABSTRACT

For an incident plane wave on an infinite plate, a doubling of mass or frequency adds 6 dB to the sound transmission loss (TL), but for an incident spherical wave on an infinite plate, a doubling of mass or frequency adds only 3 dB to the TL. In reality, the discrepancies of the sound transmission due to plane wave and spherical wave incidence might not be so huge, since the influences resulted from the plate size and the distance between the source and the plate cannot be ignored. In this article, the sound transmission of a spherical wave through a finite plate is theoretically analyzed through the modal expansion method. The transmission losses for typical plates are illustrated and as well are compared with that of the mass laws due to normal and spherical wave incidence, respectively. The effects of parameters such as the size of the plate, the distance between the source and the plate, and the horizontal shift of the plate are investigated. An indicator for the estimation of the TL through a finite plate due to a point source is given for the potential of practical applications.

1. Introduction

Sound transmission through a single-leaf plate has been widely reported [1–5]. One of the well-known features of the sound transmission through the plate is the so-called mass law. In the low frequency range or far below the critical frequency of the plate, the mass per unit area of the plate is the only plate parameter determining the sound transmission performance and a doubling of mass or frequency adds 6 dB to the TL. It also should be noted that the TL for a normal incidence on the plate is about 5 dB higher than that for a diffuse field incidence.

The mass law is usually derived from plane wave incidence on an infinite plate. Little attention has been paid to the sound transmission due to spherical wave incidence. Motoki Yair et al. [6–9] derived a mass law under the condition that a spherical wave is incident on an infinite plate. By ignoring the distance between the source and the plate due to the infinite assumption of the plate, the spherical wave incidence mass law can be described as a 3 dB increase provided that the mass per unit area or frequency is doubled. Apart from this apparent mass law difference in compare with that of normal incidence, the sound transmission loss for spherical wave incidence on the infinite plate is about 20 dB less than that due to normal wave incidence at 1000 Hz,where the critical frequency of the infinite plate is assumed much higher.

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http://dx.doi.org/10.1016/j.jsv.2017.08.020

Though the theory reveals the huge differences of sound transmission properties due to plane wave and spherical wave incidences, in reality the plate is always in finite size and the influences resulted from the plate size and the distance between the source and the plate cannot be ignored. It is therefore interesting to examine how these parameters affect sound transmission through a finite plate due to spherical wave incidence. In this article, the task started from the development of a numerical approach on how to predict the sound transmission of a spherical wave through a finite plate. Then it is followed by numerical analysis and discussion in Section 3. The TL for typical plates is illustrated and the effects of parameters are discussed. Finally, an indicator for the estimation of the TL through the finite plate due to spherical wave incidence is proposed and it might be useful in practical situations.

2. Theory

Consider a simply supported, rectangular plate lying in the plane, $z = 0$, occupying the region $0 \leq x \leq l_1, 0 \leq y \leq l_2$, within an infinite flat baffle. This plate is excited by spherical wave incidence from a point source, located at (x_0, y_0, z_0), as shown in Fig. 1.

The governing equation of the plate displacement is given in Ref. [4]:

$$D\left(\frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4}\right) + m_p \frac{\partial^2 w}{\partial t^2} = 2p^i - 2p^r. \tag{1}$$

Where w is the normal displacement of the plate, p^r is the acoustic pressure radiated by the plate, $D = Eh^3/12(1-\nu^2)$ is the bending stiffness, E the Young's modulus, ν the Poisson ratio, h the thickness of the plate, and m_p the surface density of the plate.

Using the modal expansion method, the displacement of the plate, the incident and the radiated sound pressure can be expanded as

$$w(x,y) = \sum_{m,n} W_{mn} \phi_{mn}(x,y), \tag{2}$$

$$p^r = \sum_{m,n} {p^r}_{mn} \phi_{mn}(x,y), \tag{3}$$

$$p^i = \sum_{m,n} {p^i}_{mn} \phi_{mn}(x,y), \tag{4}$$

Where $\phi_{mn}(x,y)$ is the (m,n)th normalized modal shape, given by

$$\phi_{mn}(x,y) = \frac{2}{\sqrt{l_1 l_2}} \sin\left(\frac{m\pi x}{l_1}\right) \sin\left(\frac{n\pi y}{l_2}\right). \tag{5}$$

Substituting Eqs. (2)–(4) into Eq. (1), and taking the loss factor of the plate into consideration, it reads

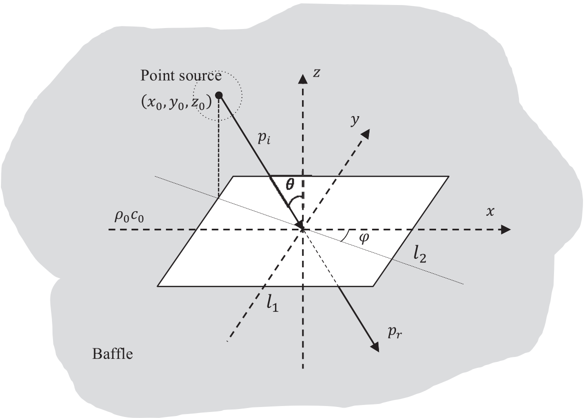

Fig. 1. Schematic of a spherical sound wave transmission through a rectangular plate.