Journal of Sound and Vibration 375 (2016) 38–52

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

Scattering of flexural waves by a pit of quadratic profile inserted in an infinite thin plate

Omar Aklouche [a,b,*], Adrien Pelat [b], Sylvain Maugeais [c], François Gautier [b]

[a] Institut de Recherche Technologique Jules Verne, Chemin du Chaffault, 44340 Bouguenais, France
[b] Laboratoire d'Acoustique de l'Université du Maine, UMR CNRS 6613, Avenue Olivier Messiaen, 72085 Le Mans, France
[c] Laboratoire Manceau de Mathématiques, Université du Maine, Avenue Olivier Messiaen, 72085 Le Mans, France

ARTICLE INFO

Article history:
Received 2 July 2015
Received in revised form
25 April 2016
Accepted 26 April 2016
Handling Editor: G. Degrande
Available online 6 May 2016

Keywords:
Flexural vibration
Wave scattering
Acoustic black hole
Trapped modes

ABSTRACT

An acoustic black hole (ABH) is a pit of power law profile inserted in a plate with internal damping. Such a pit with varying thickness leads to local variations of wave propagation properties and has been found to be an efficient vibration damper. In this paper, the ABH is seen as a penetrable obstacle and is studied through its scattering properties. A wave based model is developed within the framework of the Kirchhoff theory for a thin plate of locally varying thickness. It is shown that analytical solutions can be found in the case of a pit of quadratic profile and for uniform damping properties (without added layer). A major outcome of the model is the derivation of the dispersion relations giving a detailed analysis of the behavior of the waves within the ABH. Particularly, cut-on frequencies below which no wave propagates within the ABH are derived and thus give interpretation of the well known typical ABH efficiency threshold frequency for damping vibrations. The analysis is led from numerical computations of the dispersion curves, the scattering diagrams and the scattering cross-section, which are compared to the case of a simple hole. The results show that the ABH behaves as a resonant scatterer, which is a key outcome of this study. The so-called trapped modes, which describe free damped oscillations of the ABH, are responsible for variations of the scattering cross-section with frequency. These variations are investigated thanks to a parametric study on the geometrical properties of the ABH.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

The lightening of mechanical structures constitutes a major practical issue in transport industry and in mechanical engineering since it generally leads to an increase in vibrational and acoustical levels. The usual passive methods, based on the use of viscoelastic coatings, cannot always be used due to the additional mass they involve. In this context, a proposition consists in modifying the geometry of the structure to provide the so-called acoustic black hole (ABH) effect able to lead to large reduction of vibrational levels without mass increase of the structure. The ABH effect is related to bending wave properties in a beam of decreasing thickness and has been first theoretically shown by Mironov [1] in the context of geometrical acoustics. At the neighborhood of the edge of a beam, if the thickness smoothly decreases, the wave slows down. If the thickness profile follows a power law and the thickness strictly vanishes at the edge, it can be shown that the needed travel time for a wave to reach the edge becomes infinite.

* Corresponding author at: Laboratoire d'Acoustique de l'Université du Maine, UMR CNRS 6613, Avenue Olivier Messiaen, 72085 Le Mans, France.
E-mail address:

http://dx.doi.org/10.1016/j.jsv.2016.04.034
0022-460X/© 2016 Elsevier Ltd. All rights reserved.

Thus, the wave is not reflected at the edge and the reflection coefficient vanishes. In practice, ABH manufacture always involves non-zero residual thickness at the edge (called truncation thickness) never small enough and so the reflection coefficient of the ABH area becomes large. Krylov showed [2] that the addition of a thin layer of viscoelastic material at the extremity can significantly reduce the effect of the truncation. This idea has been extended to two-dimensional structures at the edge of rectangular plates [3,4] or inserted on plates of various geometries [5], which provide particularly attractive reductions of vibrational levels [6,7].

When an incident wave interacts with an obstacle, a scattering phenomenon occurs: the obstacle behaves as a secondary source that radiates waves going out of itself. Over the last century, wave scattering by different kinds of obstacles has been extensively studied: Morse and Feshbach [8] gave the general theoretical framework for analyzing the scattering from cylinders and spheres of both electromagnetic and acoustic waves. An application to the case of flexural waves in thin plates has been done by Mow and Pao [9] within the framework of the Kirchhoff theory to analyze scattering from a circular rigid inclusion. Norris and Vemula [10] studied analytically the scattering properties of soft and rigid obstacles inserted in an infinite thin plate. They gave results for the limiting cases of a circular rigid inclusion and a simple hole. The same authors [11] also analyzed the same scatterers within the framework of the Mindlin plate theory and pointed out the difference between these two plate theories. Squire and Dixon [12] applied a similar method to analyze the flexural wave scattering from a coated cylindrical obstacle in an infinite thin plate. In this case, since the scatterer is penetrable, the coupling between internal and external displacement fields is described by the continuity relations at the interface. The ABH belongs to this class of penetrable scatterers, for which there exists a field internal to the obstacle.

Although O'boy and Krylov [13] developed a numerical approach to the calculation of mobilities for a circular plate with a central ABH, a theoretical description of the more general problem of the scattering of an incident plane wave from an ABH is not available in the literature. This paper aims to apply the theoretical formulation from [10] to the particular case of a penetrable scatterer that consists of a circular pit of quadratic profile inserted in an infinite plate of uniform thickness. In order to reach a detailed understanding of the wave field inside and around the ABH, an analytical solution of the problem is sought. Such an analytical solution requires the power-law profile to be quadratic and of uniform material properties, that is without added damping layer. Hence, the physical understanding provided by this work would then be useful to develop other numerical approaches dedicated to the design of ABH inserted on industrial mechanical structures.

In Section 2, the governing equations are presented and the resolution method is developed to model the scattering from an ABH. The known case of a simple hole is also recalled to be compared with the ABH case. In Section 3, results from the model are presented to analyze the main ABH scattering characteristics. Trapped modes are obtained and are studied in more detail in Section 4. Parametric studies of the scattering properties are reported in Section 5. The conclusion finally gives the main outcomes and further work.

2. Model of flexural wave scattered by a circular acoustic black hole

2.1. Statement of the problem

An infinite plate of constant thickness h_0, made of a material of mass density ρ, complex Young's modulus E^* and Poisson's ratio ν, is considered. A circular scatterer of external radius b is placed at the origin of a polar coordinates system (r, θ). This scatterer can be a simple hole (Fig. 1(a)) or an ABH of external radius b and internal radius a (Fig. 1(b)).

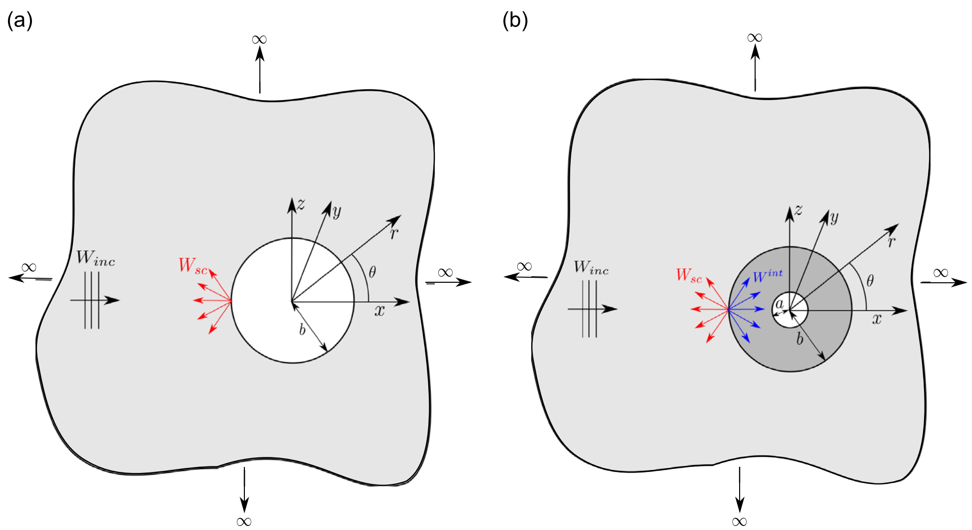

Fig. 1. Scheme of the problem: scattering of an incident bending plane wave due to (a) a simple hole or (b) an acoustic black hole inserted in an infinite thin plate.

Download English Version:

https://daneshyari.com/en/article/286940

Download Persian Version:

https://daneshyari.com/article/286940

Daneshyari.com