ARTICLE IN PRESS

Journal of Sound and Vibration xxx (2018) 1–25

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

Acoustical modeling of micro-perforated panel at high sound pressure levels using equivalent fluid approach

Zacharie Laly [a,*], Noureddine Atalla [a], Sid-Ali Meslioui [b]

[a] GAUS, Department of Mechanical Engineering, Université de Sherbrooke, Sherbrooke, Quebec, J1K 2R1, Canada
[b] Acoustics, Pratt & Whitney Canada, Longueil, Quebec, J4G 1A1, Canada

ARTICLE INFO

Article history:
Received 26 January 2017
Received in revised form 25 August 2017
Accepted 14 September 2017
Available online xxx

Keywords:
Acoustic impedance
Nonlinear model
Micro-perforated panel absorber
Equivalent fluid approach
Experimental measurements
Sound absorption

ABSTRACT

An acoustic impedance model to characterize micro-perforated panels at high sound pressure levels is proposed. The model uses a rigid frame porous medium, where the micro-perforated panel is modeled with an effective density, function of the frequency following the approach of Johnson-Allard and the equivalent fluid parameters such as the tortuosity and the flow resistivity are expressed as function of the incident sound pressure which is considered as a main variable. Unlike existing models which are limited to micro-perforated panels coupled to air cavity, the present model predicts correctly the acoustic response of micro-perforated panel backed by porous media which can be air cavity, porous material or resistive screen. Micro-perforated panel backed by porous media involves a distortion of the flow caused by the perforations through the porous media, thus the micro-perforated panel is modeled in this case using an equivalent tortuosity where a correction term is proposed to account for the flow distortion effect and it depends on the dynamic tortuosity of the porous layer and the incident sound pressure. The proposed impedance model is compared numerically with other existing nonlinear impedance models for different configurations of the micro-perforated panel. The results show a good agreement among each other for sound pressure levels up to 150 dB. In addition, experimental measurements were performed on several micro-perforated panels backed by air cavities or porous material using the classical impedance tube. A good correlation between theoretical and experimental results is obtained. Some validation and benchmarking results are illustrated and discussed in this paper. It is shown that the high sound pressure levels decrease the tortuosity and increase the flow resistivity of the micro-perforated panel. Furthermore, the acoustic energy dissipation by the micro-perforated panel absorber with a large perforation diameter which is low in the linear regime can become important and interesting at high sound pressure level.

1. Introduction

Micro-perforated panel (MPP) unlike ordinary perforated panel where the perforations are in order of millimeters or even centimeters is a panel where the perforations are reduced to submillimeter size to generate more acoustic resistance with a low perforation ratio and low acoustic mass reactance. In many application fields such as civil engineering, exhaust systems

* Corresponding author.
E-mail address: Zacharie.Laly@Usherbrooke.ca (Z. Laly).

https://doi.org/10.1016/j.jsv.2017.09.011
0022-460X/

and ducts, architecture, transportation industry and aeronautic, MPP is widely used for noise reduction. In turbofan engine, the nacelle is lined with the acoustic liners made of a thin layer (MPP or wire-mesh), a cellular separator such as honeycomb and a rigid backplate in order to reduce the engine fan noise. Conventional porous materials like foams and fibres are flammable and difficult to maintain and cannot be used in environments with a temperature gradient while the MPP can withstand high temperatures. The MPP absorber presents an interesting sound absorption in low and medium frequency.

In linear regime, different theoretical and experimental approaches were carried out to characterize the acoustic properties of the MPP. Atalla and Sgard [1] and Atalla et al. [2] modeled the MPP as an equivalent fluid using Johnson-Allard method [3] for a rigid frame porous material. Maa [5] developed an acoustic impedance model of MPP based on Crandall's theory [6] for the acoustic wave propagation in short and narrow circular tubes. The absorbent system constituted of MPP backed by an air cavity and rigid wall can be assimilated to a distribution of Helmholtz resonator [3] with viscous and thermal dissipation on the surfaces and the neck. The effect of interaction between perforations on the acoustic properties of the MPP absorber is analysed by some authors [7,13]. The sound absorption mechanism in the linear regime is the conversion of acoustic energy into heat through friction by viscous and thermal effects when the dimensions of the perforations are in the order of viscous and thermal boundary layers thicknesses.

Several studies [4,8–21,28] were published on the acoustic nonlinear effects of orifices. Maa [8] explained that the acoustic non linearity of an orifice is an external phenomenon and proposed a nonlinear acoustic impedance model of the MPP where the specific nonlinear resistance expression is the Mach number in the perforation of the MPP divided by the percentage open area (POA). Ingard and Labate [9] noted the jet formation and vortex at the exit of orifices by investigating circulations in air caused by sound waves. They showed the existence of pulsatory effects resulting in the formation of jets and vortex rings at high sound pressure levels (SPL). The nonlinear properties of the acoustic impedance of an orifice are closely connected with the circulation effects. Ingard and Ising [10] investigated experimentally the nonlinear acoustic behavior of an orifice by measuring simultaneously with a hot wire the flow velocity in the orifice and the acoustic pressure fluctuations. In the linear regime, they showed that the relation between the pressure and velocity amplitudes was linear but at large velocity amplitude, it approached a square-law relation and in this region, the acoustic resistance of the orifice dominated and varied linearly with respect to the orifice particle velocity. Furthermore, they demonstrated by their measurements at high SPL the flow separation through the orifice in the form of a high velocity jet. Ingard [11] computed the nonlinear absorption characteristics of a resonator absorber as a function of frequency. He proposed a nonlinear resistance of an orifice which is dependent upon the acoustic particle velocity in the orifice. Guess [12] determined the parameters of a single layer perforated plate by a mathematical procedure leading to elaboration of a specific acoustic resistance and reactance of MPP. Melling [13] developed a theoretical modeling of the impedance of perforates at higher levels based on a quasi-steady approximation to the acoustic flow through the orifice. This approach yields a formula for the nonlinear acoustic resistance that depends on the discharge coefficient. Chang and Cummings [14] and Cummings [15,16] studied the acoustic behavior of orifices at high SPL using a time domain approach. They presented one dimensional numerical model for the perforated plate. Kraft et al. [17,18] worked on acoustic treatment panels for high SPL leading to development of an impedance model of MPP where the resistance and the reactance are independent of frequency. Hersh et al. [19] derived one dimensional empirical impedance model for Helmholtz resonators constructed with circular orifices. The resonator geometry and incident sound pressure amplitude are considered in the model. Tayong et al. [20] proposed a model based on dimensional analysis and Forchheimer's law to investigate the acoustic behavior of MPP at high pressure excitation. Recently, Soon-Hong PARK [21] developed an empirical acoustic resistance model of a MPP which is given as a function of the incident sound pressure and the parameters of the MPP such as the thickness of the panel, the diameter of the orifice and the perforation ratio.

In this paper, an acoustic impedance model for predicting the acoustic response of MPP in high sound pressure environment is presented in section 3. The model is an extension of the linear equivalent fluid impedance model developed by Atalla and Sgard [1]. The parameters of the linear impedance model are modified to account for the nonlinear phenomena induced by the high SPL. The flow resistivity and the tortuosity of the MPP are shown to be dependent upon the acoustic particle velocity in the orifice and are expressed as functions of the incident pressure on the surface of the perforations. The main variable in the model is the incident pressure. The proposed model is verified by comparison with others nonlinear existing models and experimental results in sections 4 and 5. In section 6, micro-perforated panels backed by porous media are modeled and tested experimentally. Unlike existing models which are limited to MPP backed by an air cavity, the present model predicts well the acoustic properties of MPP at high SPL and couples with various domains such as an air cavity, a porous material or a resistive screen. When a porous media backs the MPP, a correction to the equivalent tortuosity is proposed to account for the effect of the flow distortion caused by the perforations through the porous media. Finally, section 7 presents the effect of the high SPL on the acoustic behavior of the MPP absorber. It is demonstrated that the increase in SPL causes a decrease of the tortuosity while the flow resistivity increases and the nonlinear phenomena dissipate acoustic energy so that a MPP absorber with a large orifice diameter which is not efficient at low pressure levels can be a good absorber at high SPL.

2. Review of acoustic impedance models of MPP at high SPL

Cummings [15] noted that the loss of acoustic power at the orifice is consistent with the transfer of this power into the kinetic energy of two trains of ring vortices shed alternately from both sides of the orifice. Ingard and Labate [9] explained that the nonlinear absorption of a sound wave is due to the presence of circulation effects; in the jet region, the acoustic energy is

Please cite this article in press as: Z. Laly et al., Acoustical modeling of micro-perforated panel at high sound pressure levels using equivalent fluid approach, Journal of Sound and Vibration (2018), https://doi.org/10.1016/j.jsv.2017.09.011