Applied Acoustics 73 (2012) 781–790

Contents lists available at SciVerse ScienceDirect

Applied Acoustics

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

Panel of resonators with variable resonance frequency for noise control

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ARTICLE INFO

Article history:
Received 31 August 2011
Accepted 17 February 2012
Available online 17 March 2012

Keywords:
Resonators
Liner
Neck geometry
Hole profiles
Acoustic impedance
Active noise control

ABSTRACT

The article focuses on acoustic resonators made of perforated sheets bonded onto honeycomb cavities. This kind of resonators can be used in adverse conditions such as high temperature, dirt and mechanical constraints. For all these reasons, they are, for example, widely used in aeronautic applications. The acoustic properties are directly linked to the size, shape and porosity of holes and to the thickness of air gaps. Unfortunately, the acoustic absorption of these resonators is selective in frequency and conventional acoustic resonators are only well adapted to tonal noises. In case of variable tonal noise, the efficiency is limited if the resonators are not tunable. One common solution is to control the depth of cavities based on the noise to be attenuated. This article proposes another technology of tunable resonators with only a very small mass and size increase. It consists of two superposed and identically perforated plates associated with cavities. One plate is fixed and bonded to the cavities and the other plate is mobile. The present concept enables to change the internal shapes of the holes of the perforated layers. The article describes this system and gives a theoretical model of the normal incidence acoustic impedance that allows to predict the acoustic behavior, in particular the resonance frequency. The model shows that the resonance frequency varies with hole profiles and that the absorption peak moves towards the lower frequencies. The proposed model is validated by measurements on various configurations of resonators tested in an impedance tube. The perspectives of this work are to adapt the hole profiles using an actuator in order to perform active control of impedance.

1. Introduction

The article focuses on acoustic resonators made of perforated sheets bonded onto honeycomb cavities. This kind of resonators can be used in adverse conditions such as high temperature, dirt and mechanical constraints. For all these reasons, they are, for example, widely used in aeronautic applications. The acoustic properties of such resonators are directly linked to the size, shape and porosity of holes and to the shape and thickness of air gaps as shown in many studies [1–11]. Unfortunately, the acoustic absorption of these resonators is selective in frequency and the acoustic resonators are only well adapted to tonal noises. In case of variable noise, the efficiency is limited if resonators are not tunable. The resonators under study in this article are formed by cavities connected to small ducts (called necks). The geometry of necks or cavities can be modified in order to produce tunable resonators.

Many studies deal with the cavity depth change. Konishi et al. [2] and Birdsong and Radcliffe [3] proposed tunable acoustic absorbing systems made of resonators the porosity or air cavity volume of which are controllable so as to tune the resonant frequency to a desired frequency. Kostek and Franchek [4] studied the control of such systems. Kobayashi et al. [5] successfully implemented resonators with tunable cavities in a turbofan.

In this study, the neck geometry of the resonators varies rather than the cavity size. All works about hole geometry show its impact on the acoustic behavior of resonators. The length, shape and section of the neck have an impact on the surface impedance, in particular the reactance. As the sound absorption coefficient is maximum when the reactance is null, the neck has an influence on the frequency resonance of the resonators.

Birnbach et al. [6,7] studied a resonator with two perforated plates and an inlet air gap. They studied different configurations with variable distance between plates. For a very small distance from 0.05 mm to 0.1 mm, the resonators show high acoustic impedance and low absorption. By increasing the distance between the plates, the impedance decreases and the absorption becomes maximum.

Chanaud [8] studied the radiation impedance for geometries of non-circular orifices. He examined the cross orifice made up of two rectangular shapes placed perpendicular to each other. He calculated an equivalent circular orifice because no solution could be found for rectangular radiation piston. He also studied the

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doi:10.1016/j.apacoust.2012.02.011

Nomenclature

l_1	thickness of plate 1
l_2	thickness of plate 2
ℓ_1	length correction of plate 1 (effective length)
ℓ_2	length correction of plate 2 (effective length)
ℓ_E	length correction in the elliptic constriction (effective length)
L	cavity depth
δ_e	exterior mass end correction
δ_i	interior mass end correction
V_1	volume of air considered in motion in plate 1
V_E	volume of air considered in motion between plates 1 and 2
V_2	volume of air considered in motion in plate 2
V'_1	volume of air supposed lost in plate 1
V'_1	volume of air supposed lost in plate 2
S_1	hole diameter in plate 1
S_2	hole diameter in plate 2
S_E	section of elliptic constriction between plates 1 and 2
b	semi-major axis
a	semi-minor axis
ϕ	porosity
D	mobile plate displacement
p	acoustic pressure
R	normalized acoustic resistance
X	normalized acoustic reactance
Z	normal incidence acoustic impedance ($Z = R + jX$)
ω	angular frequency pulsation
c	sound speed
k	wave number equal to ω/c.
ρ_0	ambient density

interaction of the orifice shape on the end correction. He concluded that the orifice shape did not significantly affect the interior mass end correction.

Ducts' end effects have been also investigated by [9–11]. These studies have shown that edges' end effects generate nonlinearities with high sound pressure levels and that the duct thickness and the duct edge shape have an influence on both resistance and reactance of orifices. Some of these effects can be taken into account in the modeling. The corrections that make models more accurate can be computed for different shapes, in particular for round edges' duct ends.

Tang [12] studied a resonator with a tapered neck. Results show that the resonance frequency increases with the tapering length and that absorption increases with the tapered neck slope.

The general conclusion of all previous studies is that controlling the opening size or the shape of resonators necks can be a way to control the impedance and thus the efficiency of resonators. This article studies a simple system to modify the neck geometry. The system tries to satisfy aeronautical constraints by nearly not increasing the weight and size of conventional resonators. It consists of two stacked perforated plates bonded onto cavities. Perforations are circular and the plates are identically perforated. One plate is fixed and the other is mobile in translation and can slide on the first one. The holes are aligned if there is no movement; this case corresponds to conventional resonators with cavities and a perforated plate with a thickness equal to the thickness of the two plates. If the mobile plate displacement makes the two perforated plates overlap, new neck geometry with a nearly elliptic shape is created by the constriction between the two perforations. This constriction affects the effective volume of air in motion and then the acoustic impedance.

Section 2 accurately describes the developed system.

Section 3 aims at proposing a model of the system and in particular of the two perforated plates versus the translation. It gives the expressions of the reactive and resistive parts of the normal incidence impedance using an equivalent geometry of the two overlapping plates and a simplified phenomenological approach essentially based on Ingard's model [13] and on Rayleigh's conductivity [14]. The impedance is determined using lumped parameter modeling with low frequency approximation in one dimension.

Section 4 describes the experimental set-up and gives the experimental results. Tests are performed in an impedance tube for several cases corresponding to aeronautics configurations used in jet engines noise control (porosities equal to 2.5%, 5% or 10%, perforated hole diameters equal to 1 mm or 2 mm and plates' thicknesses equal to 1 mm or 2 mm). The tests make it possible to validate the model described in Section 3 and the efficiency of the proposed system.

2. System description

The system under study in this paper is composed of resonators formed by two stacked perforated plates backed by cylindrical cavities (Fig. 1). Plate 1 is fixed and plate 2 is mobile. The fixed plate is bonded onto cavities and the mobile plate, on the top, can move by translation in one direction. The perforations and the porosity of the two plates are identical. The hole diameter is $2r$. The overlap must be performed with accuracy and the plates are thus guided on two parallel sides by two sliding rails. The translation of the mobile plate is performed in one direction by an actuator (Fig. 2). This actuator is a double-row ball bearing linear stage. The stage is fixed on the mobile plate and on the sliding rails through a link rod. Therefore, the mobile plate can be slid in and out with the smooth stage travel by a manual knob control. The translation of the mobile plate generates neck geometry with an elliptic profile as shown in Fig. 3. The translations values (D) vary from zero to the perforate hole diameter. The minimum distance between two holes is more than one diameter to avoid the case of two overlaps for the same perforation. L is the cavity depth, ℓ_1 and ℓ_2 are the thicknesses of the bottom fixed plate and of the top mobile plate respectively (Fig. 1).

3. Building a model

3.1. A model of the normal incidence acoustic impedance

The aim of this section is to establish a model of the normal incidence acoustic impedance. The impedance is an important characteristic since it enables to describe the interaction between acoustic incident waves and absorbent materials. In this model, the flow over the perforated interface is not taken into account.

The expression of the acoustic impedance of a duct with a section discontinuity (Fig. 4) can be found in many references [15–17]. The impedance is established by writing the acoustic pressure continuity:

$$p'_1 = p'_2 \tag{1}$$

and the flow conservation:

$$S_1 v'_1 = S_2 v'_2 \tag{2}$$

with v'_1 and v'_2 the velocities normal to surfaces.