Nonlinear Structuring of Helmholtz Resonators for Increasing the Range of Sound Absorption

Emmanuel GOURDON
ENTPE, Université de Lyon, LGCB & LTDS UMR CNRS 5513, Rue Maurice Audin - F- 69518 Vaulx-en-Velin Cedex - FRANCE

Alireza TURE SAVADKOOHI
ENTPE, Université de Lyon, LGCB & LTDS UMR CNRS 5513, Rue Maurice Audin - F- 69518 Vaulx-en-Velin Cedex - FRANCE

Summary
Sound absorption is usually performed by using porous materials as acoustic absorbers. These materials are not efficient in low frequencies compared to their efficiencies high frequencies. One of the solutions for absorption at low frequencies is to couple another resonators which are knows as Helmholtz resonators. The drawback of these systems is that they are valid and tuned for a very narrow frequency range. The geometry of the neck of Helmholtz resonators plays an important role in the quality and the range of sound absorption. In this work we will presents experimental results of nonlinear structured geometry of Helmholtz resonators.

PACS no. xx.xx.Nn, xx.xx.Nn

1. Introduction

Sound absorption is usually performed by using porous materials as acoustic absorbers. These materials are not efficient in low frequencies compared to their efficiencies high frequencies. One of the solutions for absorption at low frequencies is to couple another resonators which are knows as Helmholtz resonators. The drawback of these systems is that they are valid and tuned for a very narrow frequency range. The geometry of the neck of Helmholtz resonators plays an important role in the quality and the range of sound absorption. In this work we will presents experimental results of nonlinear structured geometry of Helmholtz resonators. The drawback of these systems is that they are valid and tuned for a very narrow frequency range. Recently, nonlinear strategy has been proposed and implemented to improve the performance of Helmholtz resonators for wide frequency ranges. The idea is based on “energy pumping" [1, 2, 3, 4] by using nonlinear energy sink (NES) devices. In the domain of acoustics, thin viscoelastic membrane is used as NES [5, 6, 7, 8]. There have been some attempts for improving the quality of noise absorption of Helmholtz resonators by tailoring their necks. Tang [9] experimentally studied the sound absorption performance of a Helmholtz resonator with a tapered neck. Results show that significant improvement of the sound absorption capacity of the resonators can be obtained by introducing such neck tapering. Such improvement is enhanced when the tapered length is increased [9]. In this study, we try to study a Helmholtz resonator with tailored neck in the shape of quadratic hyperbola experimentally.

2. Theoretical treatments

According to the Laplace's correction to Newton's Formula, we have:

$$\frac{dp}{p} + \gamma \frac{dV}{V} = 0 \tag{1}$$

where, p and V represent the pressure and volume of the enchased gas, respectively and $\gamma = \frac{C_p}{C_v}$ is the ratio of the heat capacity at constant pressure to heat capacity at constant volume which is called as “adiabatic index". The frequency of the sound created in the resonator is equal to that of the air's vibration and can be derived from Eq. 1 as it follows:

Table I. Characteristics of different configurations of the neck of the resonator: all units are in mm.

	H_1	H_2	H_3	H_4	H_5	H_6
$l(mm)$	8.5	8.5	8.5	8.5	8.5	8.5
$r_0(mm)$	1.5	1.5	1.6	2.75	1.7	3.25
$r_1(mm)$	1.5	2	2.75	1.6	3.25	1.7

$$f = \frac{c}{2\pi}\sqrt{\frac{S_{neck}}{V l_{neck}^{eff}}} \tag{2}$$

where S_{neck} and l_{neck}^{eff} are cross section and “effective length" of the neck of the Helmholtz resonator, respectively. c is the longitudinal propagation speed of sound in air which is evaluated as:

$$c = \sqrt{\frac{\gamma p}{\rho}} \tag{3}$$

with ρ being density of the air. Rayleigh [10] suggested following formula for evaluating the “effective length" of the neck:

$$l_{neck}^{eff} = l_{neck} + 2\delta = l_{neck} + 2\frac{8r}{3\pi} \approx l_{neck} + 0.96\sqrt{S_{neck}} \tag{4}$$

where l_{neck} is the physical length of the neck and r is the radius of the neck.

2.1. Nonlinear tailoring of the neck

Let us consider the Helmholtz resonator which is depicted in Fig. 1: The neck of the resonator is in the form of “hyperbolic quadratic" which can take one of the forms of Fig. 2. We suppose that governing equation of the neck is:

$$y = r_0 + ax^2 \qquad r_0 \leq y \leq r_1 \tag{5}$$

where $a = \dfrac{r_1 - r_0}{l^2}$.

3. Experimental results

The experimental test set up is illustrated in Fig. 3. Three microphones are positioned on the Kundt tube: no.1 and no. 2 which are placed on the 16cm and 18cm upstream of the cavity, respectively. Microphone no. 3 is mounted at the bottom of the cavity. The length of the cavity is 21.5mm. Six different configurations as the neck of the resonator are structured which are depicted in Fig. 4. Their characteristics are collected in Table I.

The system is excited by pseudo-sinusoidal excitation with different amplitudes. Figure 5 summarizes absorption corresponding to different configurations of the neck of the resonator under excitation with medium amplitude that produces a pressure of $= 250Pa$ inside the tube. It can be seen that absorption coefficient is enhanced owing to the tailored neck and the more the neck is tapered the more the coefficient gets higher. Moreover, due to the nonlinear structuring of the neck, the frequency range is enhanced. Figure 6 presents the amplitude versus frequency for three experimental points (low, medium and high amplitudes) for the H_5 configuration. This hardening behavior will allow possible targeted energy transfer and localization when this kind of resonator is coupled to a linear media.

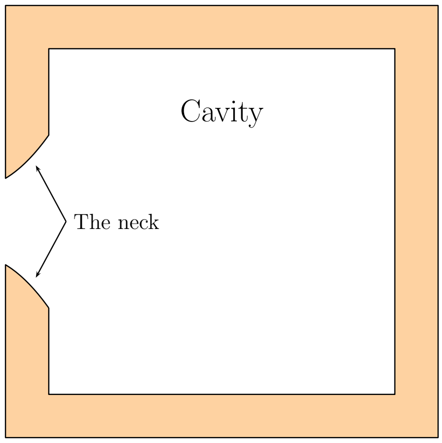

Figure 1. The Helmholtz resonator with nonlinear tailored neck.

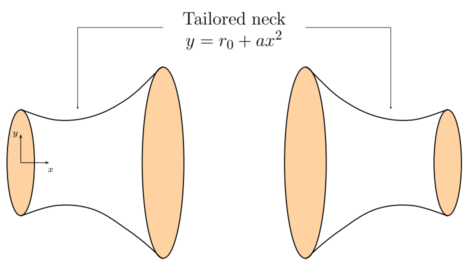

Figure 2. Proposed tailored necks of the Helmholtz resonator in the form of hyperbolic quadratic.

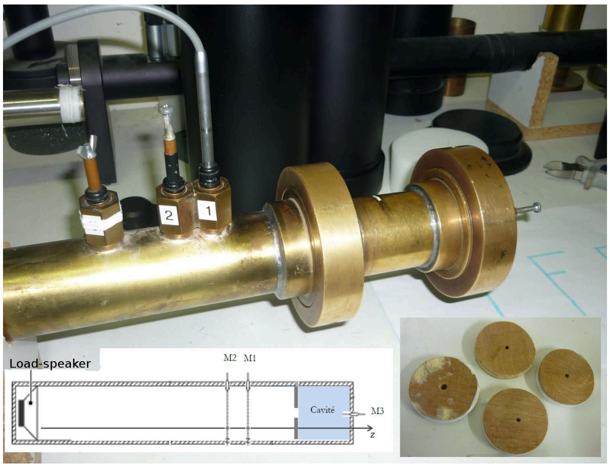

Figure 3. Experimental test set up.

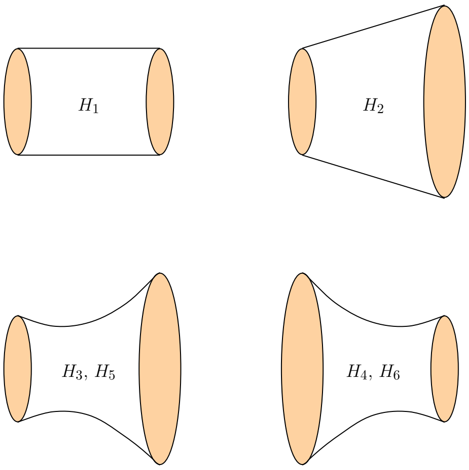

Figure 4. Different configurations of the neck of the Helmholtz resonator.

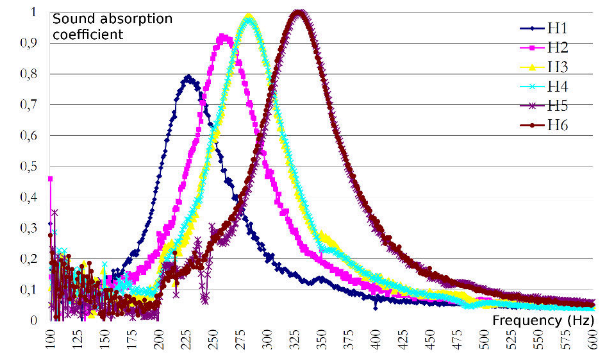

Figure 5. Absorption coefficients corresponding to different configurations of the neck excited by medium forcing amplitude.

4. CONCLUSIONS

The paper deals with the effect of nonlinear tailoring (hyperbolic quadratic form) of the neck of the Helmholtz resonators in the quality of sound absorption. A series of experimental studies are carried out on different Helmholtz resonators with different types of tailored necks including straight, linear and quadratic ones. These results show that the range of sound absorption increases by nonlinear tailoring of the neck of the resonator. This effect presents a hardening nonlinear behavior which gives a rise to the idea of the targeted energy transfer of waves of an acoustic media by coupling to nonlinear resonators. More analytical developments are going on to give us useful tools for designing nonlinear Helmholtz resonators to be used as a nonlinear system for localization of the energy of other coupled media.

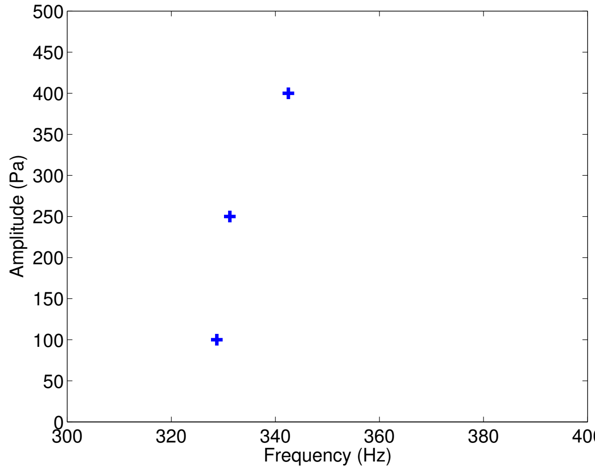

Figure 6. Three experimental results of maximum frequency versus amplitude of the excitation corresponding to the configuration H_5.

Acknowledgement

This work is supported by the French National Research Agency (ANR) in the frame of following projects: i) ANR METAUDIBLE (ANR-13-BS09-003) and ii) LABEX CELYA (ANR-10-LABX-0060) of the "Université de Lyon" within the program "Investissement d'Avenir" (ANR-11-IDEX-0007).

References

[1] O. Gendelman, L. I. Manevitch, A. F. Vakakis, R. M'Closkey: Energy pumping in nonlinear mechanical oscillators: part I - dynamics of the underlying hamiltonian systems. Journal of Applied Mechanics 68 (2001) 34-41.

[2] A. F. Vakakis: Inducing Passive Nonlinear Energy Sinks in Vibrating Systems. Journal of Vibration and Acoustic 123 (2001) 324-332.

[3] E. Gourdon, N. A. Alexander, C. A. Taylor, C.-H. Lamarque, S. Pernot: Nonlinear energy pumping under transient forcing with strongly nonlinear coupling: theoretical and experimental results. Journal of Sound and Vibration 300 (2007) 522-551.

[4] A. Ture Savadkoohi, B. Vaurigaud, C.-H. Lamarque, S. Pernot: Targeted energy transfer with parallel nonlinear energy sinks, part II: theory and experiments. Nonlinear dynamics 67 (2012) 37-46.

[5] R. Bellet, B. Cochelin, P. Herzog, P.-O. Mattei: Experimental study of targeted energy transfer from an acoustic system to a nonlinear membrane absorber. Journal of Sound and Vibration 329 (2010) 2768-2791.

[6] R. Mariani, S. Bellizzi, B. Cochelin, P. Herzog, P.-O. Mattei: Toward an adjustable nonlinear low frequency acoustic absorber. Journal of Sound and Vibration 330 (2011) 5245-5258.

[7] R. Bellet, B. Cochelin, R. Cote, P.-O. Mattei: Enhancing the dynamic range of targeted energy transfer in acoustics using several nonlinear membrane absorbers. Journal of Sound and Vibration 331 (2012) 5657-5668.

[8] J. Shao, B. Cochelin: Theoretical and numerical study of targeted energy transfer inside an acoustic cavity by a non-linear membrane absorber. International Journal of Non-Linear Mechanics 64 (2014) 85-92.

[9] S. K. Tang: On Helmholtz resonators with tapered necks. Journal of Sound and Vibration 279 (2005) 1085-1096.

[10] L. Rayleigh: On the theory of resonators. Philosophical transactions of the Royal Society (1870).