Experimental study of noise reduction using an hybrid electro-acoustic NES

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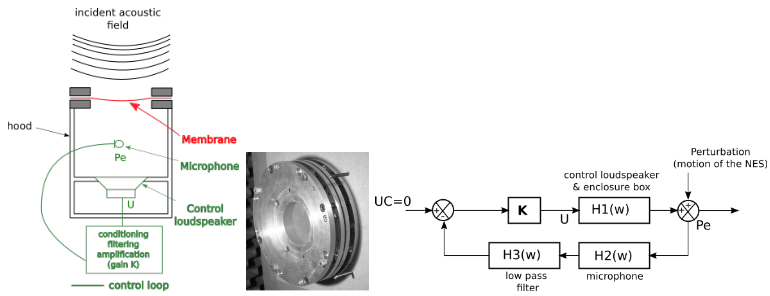
Summary. An hybrid electro-acoustic NES (hNES) is described. It is composed of an clamped membrane with one face coupled to an acoustic field and the other one enclosed. The enclosure includes a feedback loop composed of a microphone and a loudspeaker that control the pressure difference at the level of the membrane. Due to the non-linear deformation of the membrane, the hNES performs resonance capture with the acoustic field, resulting in noise reduction. The feedback loop modifies the resonance frequency of the hNES at low level, which is a key factor to tune the triggering threshold of energy pumping. An experimental study is presented including the influence of the feedback loop parameters.

Introduction

Nonlinear energy sinks (NES) are based on the principle of the "Targeted Energy Transfer" (TET) that allows to transfer the energy from a primary system to the NES[1]. Great attention has been recently paid to employing a clamped visco-elastic membrane as a acoustic NES rather than Helmholtz absorbers(see [2, 3, 4, 5]). However these studies have shown some limitations, as an excessive triggering threshold or a radiation in the high frequencies of the energy absorbed in low frequencies. The main objective of this work is to develop a family of NES to overpass these limitations.

Description of the hybrid electro-acoustic NES (hNES)

The hNES (Fig. 1) is composed of an clamped latex membrane (as in [2]) with one face (the front face) exposed to the acoustic field to be reduced and the other (the rear face) enclosed. The enclosure is used to create a pressure difference at the level of the membrane. It is primordial when the absorber has to be used to reduce the acoustic field in a cavity. The acoustic pressure P_e in the enclosure adds linear stiffness to the membrane as shown in Eq. (1) (Fig. 1). A feedback loop composed of a microphone and a loudspeaker has been added. It controls the acoustic pressure P_e seen by the rear face following the block-diagram shown in Fig. 1. In consequence, the gain K of the feedback loop tunes the resonance frequency of the hNES at low level.



$$P_e(\omega) = -\rho c^2 \frac{\Delta V_e}{V_e} \quad (1)$$

Figure 1: hNES absorber: Scheme, exterior face, the block-diagram of the feedback loop.

Experimental set-up and results

The experimental set-up consisting of the hNES coupled to a tube (with a first resonance around 87 Hz) is displayed Fig. 2. The coupled system is first studied at low excitation level (linear regime) using a wide band excitation signal. The measured transfer function $\frac{P_2}{U_{source}}$ is reported Fig. 2 for several values of the gain K. The highest value correspond to a gain margin of 1 dB for the feedback loop. Two resonance frequencies are visible, one near 87 Hz (associated to the tube) which is not affected by the gain K and the other (associated to the hNES) which is shifted from 73 Hz to 62 Hz increasing the gain K. Hence, the gain K allows to tune the resonance frequency of the hNES.
The coupled system is next studied at high excitation level (non linear regime) thanks to sinusoidal excitation signals in the frequency range $[80, 92]$ Hz and the RMS excitation level range $[0.1, 4]$ A. For the gain $K = 400$, the RMS-values of the acoustic pressure p_{tube} are reported Fig. 3 under the form of a surface level depending on the frequency and the excitation level. We recognize the zone (named the effective NES zone) where the level of excitation increases and the sound level remains limited at the same maximum. Also shown Fig. 3 using the same form of plot, the fundamental harmonic ratio conversion (FRC), the non harmonic ratio conversion (NHRC) and the harmonic ratio conversion (HRC) (see [5] for details) of the acoustic pressure p_{tube}. We observe that FRC is minimum and NHRC is maximum in the effective zone as expected in TET regime. Outside the effective zone, the FRC dominates traducing a periodic regime. However there exists a zone where HRC is not zero (but small) traducing the non-linear behaviour of the NES. These three types of regimes are plotted Figure 4.

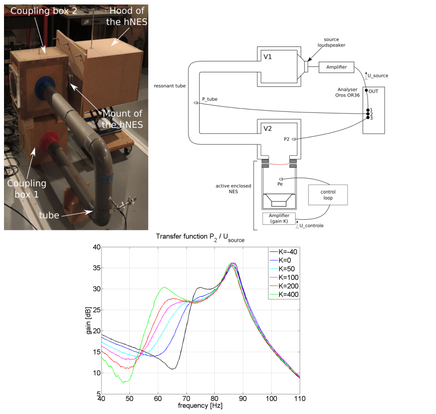


Figure 2: Picture and scheme of the set-up. (The experimental set-up consists in a vibroacoustic system (also named primary system) coupled to the hNES. The linear primary system is made of an open pipe coupled at each end to coupling boxes. One coupling box (box 1) contains a loudspeaker (the acoustic source), and the hNES is clamped on one face of the other coupling box (box 2). During a measurement, a targeted current signal $i_{\mathrm{LS}}(t)$ feeds the source loudspeaker. We record the tension $u_{source}(t)$ and the current $i_{\mathrm{source}}(t)$ applied to the source loudspeaker, the acoustic pressures $p_{tube}(t)$ at mid length of the pipe and the acoustic pressure $p_2(t)$ in the box 2.) Measured transfer function $\frac{P_2}{U_{source}}$ for several values of the gain K at low excitation level.

The last figure summarizes results obtained with several values of the gain K where the maximum RMS-value over the frequency range of the acoustic pressure p_{tube} is plotted versus the RMS excitation level range. For each curve, the effective NES zones corresponds to the plateau. The beginning (threshold) and the width of the plateau depend on the gain K. These two quantities increase with K. The dependency of the threshold with respect to K is in agreement with behaviour of the resonance frequency of the hNES (see Fig. 2).

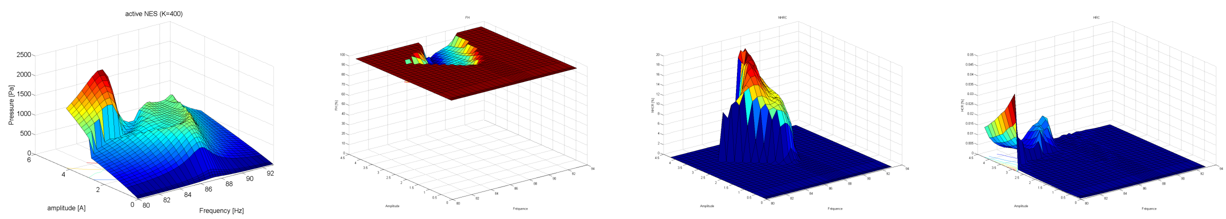


Figure 3: $p_{tube}(t)$ (RMS-values) versus frequency and excitation level. Same plot with FRC, NRHC and HRC (from p_{tube}).

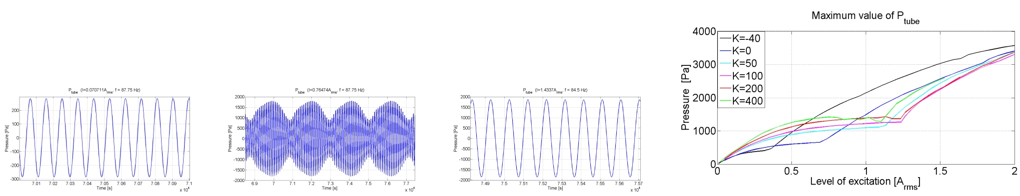


Figure 4: p_{tube} versus time for three types of regime ($K = 400$). Maximum RMS-value over the frequency range of p_{tube} versus excitation level for several gain K values.

Conclusions

We presented an new acoustic NES involving a nonlinear vibroacoustic system drove by an electro-acoustic device. Experiments were conducted demonstrating that the electro-acoustic device is able to tune the (linear) resonance frequency of the hNES. Furthermore the threshold and the width of the effective zone increase with the gain K not allowing to design a hNES with both low threshold and large width effective zone. Further work will will experiment feedback looks with variable gain.

References

[1] A. Vakakis, O. Gendelman, L. Bergman, D. McFarland, G. Kerschen, Y. Lee, Nonlinear targeted energy transfer in mechanical and structural systems, Vol. 156 of Solid mechanics and its applications, Springer, 2008.

[2] 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.

[3] 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.

[4] J. Shao, B. Cochelin, Theoretical and numerical study of targeted energy transfer inside an acoustic cavity by a non-linear membrane absorber, Journal of Sound and Vibration 64(2014)85–92.

[5] R. Côte, M. Pachebat, S. Bellizzi, Experimental evidence of simultaneous multi-resonance noise reduction using an absorber with essential nonlinearity under two excitation frequencies, Journal of Sound and Vibration 333 (2014) 5057–5076.