Characterization of a nonlinear sound absorber at low frequencies and high sound levels

M. Volpe[1], **S. Bellizzi**[1] **and R. Côte**[1]

[1]Aix Marseille Univ, CNRS, Centrale Marseille, LMA
Marseille, France
volpe@lma.cnrs-mrs.fr, bellizzi@lma.cnrs-mrs.fr, cote@lma.cnrs-mrs.fr

Abstract To characterize nonlinear acoustic loads identification techniques have been developed. A specific setup of impedance tube named "Short Kundt's Tube" (SKT) was built to reach high sound levels at low frequencies. Two approaches, developed in the frequency domain, are discussed : a linearization method giving access to the acoustic impedance and a nonlinear model which is able to characterize energy transfer to higher harmonics. Both are excitation level dependent.

Numerous sound absorbers dedicated to noise reduction at low frequencies are based on nonlinear properties, such as nonlinear vibroacoustic absorbers also known as Nonlinear Energy Sinks (see for example [1,2]). In this work, nonlinear elements are characterized at low frequencies and very high levels using a SKT [3] composed of a complex acoustic source connected to a tube wich support the device under test (DUT) (see Figure 1.(a,b)).

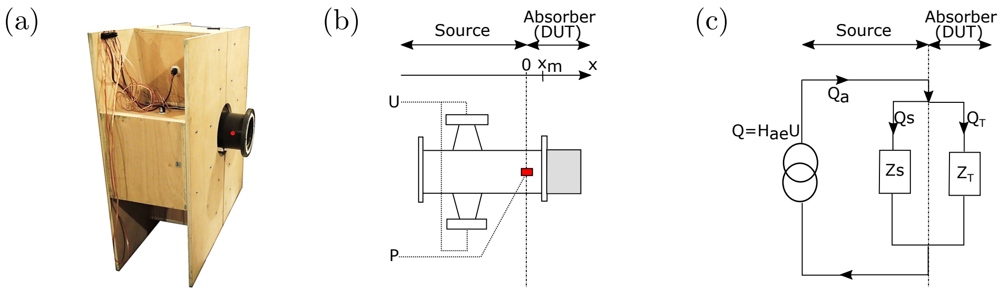

Figure 1: (a) Picture of the source. (b) Scheme of the experimental set-up and (c) the equivalent electroacoustic circuit of the one-microphone identification method.

A first identification technique is a linearization method and gives access to the acoustic impedance and/or the reflection coefficient which are excitation level dependent. After a source calibration step [3], the nonlinear DUT is characterized by an equivalent impedance $Z_T(f)$ (and the reflection coefficient $R_T(f)$). $Z_T(f)$ is definied as a linear approximation of the transfert between the pressure $P(f)$ and volume velocity $Q(f)$. They are both considered over the tube section in the measurement plane (see Figure 1.(c)). Two nonlinear acoustic absorbers, a thin viscoelastic circular membrane and the same membrane with a plywood box clamped on its rear face described in [2], have been studied. We observe that resonance frequencies of the two absorbers increase with the excitation level, characterizing a nonlinear behaviour of the systems and their hardening nature. Moreover, the energy extracted by the absorbers increase with the excitation level, over a frequency range widening.

A second technique is based on a nonlinear model which is able to characterize energy transfer to higher harmonics, by defining an impedance or a scattering matrix [4]. We assume that the acoustic source generates an excitation at only one frequency f (the fundamental frequency). The impedance formulation of multi-port model characterizes the relationship between the harmonic terms ($P_n(f)$) of the acoustic pressure at the microphone position and the harmonic terms ($Q_n(f)$) of the corresponding acoustic volume velocity as

$$P_n(f) = \sum_{k=1}^{\infty} Z_{nk}(f, |P_1(f)|) Q_k(f) \text{ for } n = 1, 2, \cdots \quad (1)$$

The impedance term, $Z_{nk}(f, |P_1(f)|)$, represents the opposition at the frequency nf that the acoustic load presents to the acoustic flow at the frequency kf from a source signal at frequency f. This term depends on the excitation frequency f and on the amplitude level of the acoustic pressure represented by $|P_1(f)|$ (amplitude of the first harmonics). An equivalent formulation can be obtained using a scattering-matrix approach and Eq.(1) can be simplified by assuming that energy exchange can occur only from low to high frequency and that the DUT satisfies the harmonic superposition principle [5]. This method has been applied to an adjustable nonlinear acoustic absorber, made of a loudspeaker membrane described in [1]. Coefficients of the impedance matrice are reported Figure.2. Nonlinear behaviour of the absorber is visible on $|Z_{11}|$ where we can observe the frequency shift of the apparent resonance when the excitation level increases (see Figure2.(a)). $|Z_{22}(f)|$ is equivalent to a $|Z_{11}(f)|$ associated to a lower excitation level (level of $P_2(f)$) and shifted in frequency with a ratio of $f/2$ (see Figure.2(b)). Finally, $|Z_{21}|$ shows the transfer of energy between the fundamental and the second harmonics, which increases with the excitation level (see Figure.2(c)).

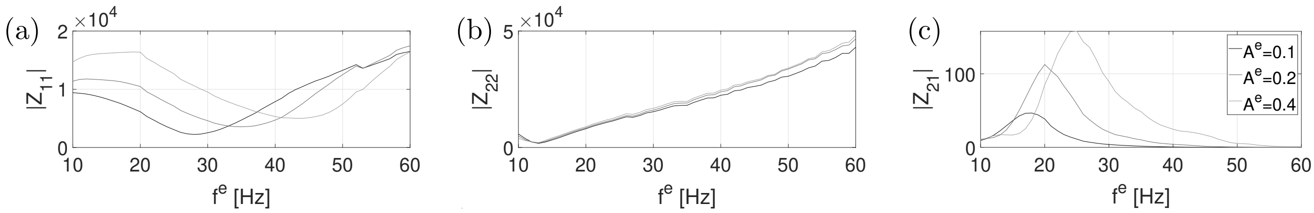

Figure 2: Estimation of impedance coefficients for three excitation levels.

These experimental results have been compared to numerical simulations results. In future works the quantification of energy transfer will be done with a larger number of harmonics, in order to quantify all the wave conversions present in the tube. A synchronized swept-sine method will be developed to improve experimental procedure.

References

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