Noise control via exploiting nonlinear interactions

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Summary. Nonlinear behaviours of acoustical resonators, such as Helmholtz resonators in nonlinear regimes [1] or electroacoustic absorbers [2], are used to obtain targeted energy transfer [3] from an acoustical mode to the resonators. It is shown that the noise control is carried out via nonlinear interactions between acoustical mode and the absorbers leading to periodic or modulated regimes.

Nonlinear noise control

Let us consider an acoustical resonator which is composed of a cavity (container of the air) and the orifice (the neck). If the length of the neck is smaller than the wavelength, then the overall system can be modelled as a mass-spring oscillator where the lumped mass is in fact the encased mass of the air in the orifice while the air inside the cavity acts as the spring. With analogy of mechanical engineering, we are interested to create a nonlinear restoring forcing function which can be coupled to an acoustical mode for creation of acoustical energy tunnelling between the mode and the resonator with nonlinear responses.

Nonlinear behaviours of the acoustical resonator

Figure 1 depicts different geometries of the neck of the resonator: The classical straight neck (H_1) of the acoustical resonator is tailored in a linear (H_2) and quadratic manner (H_3). Table 1 summarises dimensions of each configuration while the length of the cavity for all case is 25 mm. The resonators are coupled to the Kundt tube [4] and the system is excited by different sinusoidal forces while the pressures inside the cavity during the resonance are measured. All resonators show three regimes categorizing as linear, almost linear and nonlinear. Moreover, it is seen that tailoring the geometry of the neck accelerates reaching to the nonlinear domain. The actual limitation of current study is that even via tailoring the system, it reaches to the nonlinear domain at high sound pressure levels, around 125-130 dB. There are ongoing works to reduce this pressure level so that the proposed system can be applied for buildings.

	H_1	H_2	H_3
l	8.5	8.5	8.5
r_0	1.5	1.5	1.7
r_1	1.5	2	3.25

Table 1: Characteristics of different configurations of necks (mm). l stands for the length of the neck.

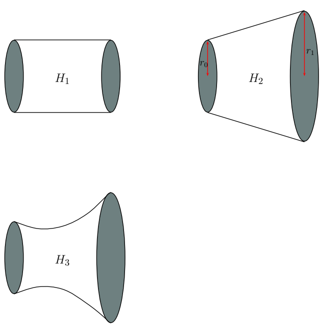

Figure 1: Considered geometries for the neck of the resonator.

The governing equation of the acoustical resonator can be represented by following equation (see for example [5]):

$$\frac{\mathrm{d}^2 x}{\mathrm{d}t^2} + \sigma \frac{\mathrm{d}x}{\mathrm{d}t}\left|\frac{\mathrm{d}x}{\mathrm{d}t}\right| + \delta \frac{\mathrm{d}x}{\mathrm{d}t} + \left(x - \alpha x^2 + \beta x^3\right) = -p \tag{1}$$

Equation 1 shows that the system possesses linear and nonlinear damping terms together with the linear, quadratic and cubic (until third order developments) restoring forcing function. This system has been studied in detail by Alamo Vargas et al. [1] for different excitation terms p showing that it can present softening and hardening behaviours. The idea is to couple this resonator with nonlinear responses (or other resonators such as electroacoustic absorbers with similar behaviours) to an acoustical mode for nonlinear noise control. The next section discusses about noise control via proposed system.

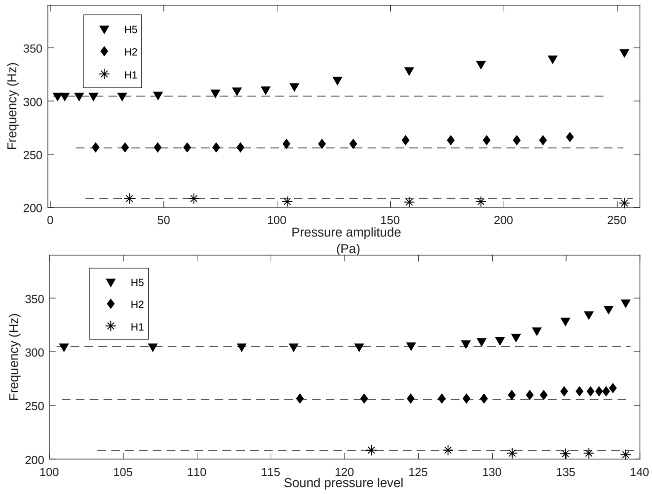

Figure 2: Variations of resonant frequency versus pressure amplitude (Pa) and sound pressure level (dB) inside the cavity.

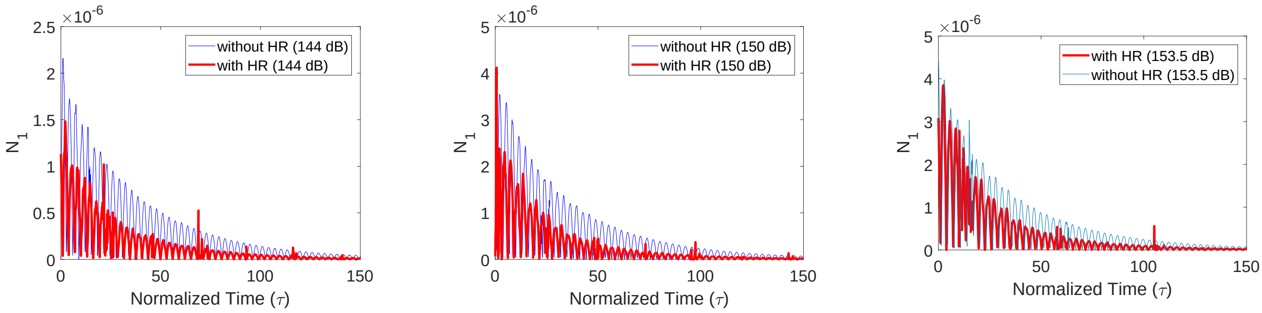

Figure 3: Free vibration responses at the middle of the tube for different excitation amplitudes. These amplitudes create pressures of 144 dB, 150dB and 153.5dB at the bottom of the cavity of the resonator [6]. N_1 stands for the amplitude of the acoustical mode.

Passive noise control: coupling an acoustical mode to the resonator with nonlinear response

The explained resonator in previous section is coupled to a tube via a coupling box [6]. The first acoustical mode of tube with the frequency of 378.6Hz has been generated. For creation of the free vibration, several sinusoidal signals with the frequency of 378.6Hz are sent, then stopped and measurements are registered. Experimental results are collected in Fig. 3. It is seen that the resonator is capable of controlling the acoustical mode. Moreover, the control process is carried out in two global phases: the first part is via nonlinear interactions between oscillators and second part which is similar to the energy reduction by classical damped systems. Analytical developments are also carried out showing that the system can be attracted by periodic [7] or modulated [8] regimes. Results are collected in [6].

Conclusions

It is shown that via changing the geometry of the classical resonator, the emergence of the nonlinear behaviours of the resonator will be accelerated. Moreover, via coupling this resonator to an acoustical mode, it is possible to create a noise control via exploiting nonlinear interactions between oscillators. There is an ongoing work which deals with creation of nonlinearities via electric circuits for acceleration of noise control.

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