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

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Context and Aims

Issues:
- Noise reduction at low frequency and high sound level
- Requirement of a characterization method for nonlinear sound absorbers
  ex: microperforated panels, dynamic absorbers like Nonlinear Energy Sink (NES)

Aims:
- Development of a set-up for the characterization of non-linear acoustic absorbers
  ➔ Short Kundt Tube (SKT)

Linearization method [3]

Aim: Characterization of acoustic loads in term of apparent impedance ($Z_T$) or apparent reflection coefficient ($R_T$)

- From measurement of transfer function $H_m(f)$ between $u(t)$ and $p(t)$
- Excitation with synchronized sweep sine, for different excitation levels
- Equivalent linear loads characteristics from electroacoustic model:
  \[
  Z_T = \frac{H_m Z_0}{H_m Z_0 - R_T} \quad R_T = \frac{H_m Z_0 - Z_m (H_m - H_m)}{H_m Z_0 - Z_m (H_m - H_m)}
  \]

- Applications to nonlinear absorbers:
  ➔ At low level: linear behaviour
  ➔ Beyond: resonance frequency shift towards high frequencies

Method by nonlinear signature

Aim: Taking nonlinearity signature into account in the characterization of acoustic absorbers

- Extension of the notion of reflection coefficient to nonlinear systems in terms of scattering matrix

\[
\begin{pmatrix}
P_{11}(f) & \cdots & P_{1n}(f) & \cdots & P_{1N}(f) \\
\vdots & & \vdots & & \vdots \\
P_{n1}(f) & \cdots & P_{nn}(f) & \cdots & P_{nN}(f) \\
\vdots & & \vdots & & \vdots \\
P_{N1}(f) & \cdots & P_{Nn}(f) & \cdots & P_{NN}(f)
\end{pmatrix}
\]

- Relation between $N$ harmonics of incident pressure $p^\ast(t)$ and backward pressure $p^\ast(-t)$
- Note: for a linear load, scattering matrix reduces to $S_{11}(f)= R_T(f)$

Notation: $P_{nf}(f)$ is the $n$th harmonic of the fundamental frequency $f$ of the backward pressure wave $p^\ast(-t)$ emitted by the load (respectively $P_{nf}(f)$ for the incident pressure $p^\ast(t)$)

- Estimation of the scattering matrix using stepped sines (mode 1) and synchronized sweep sine (mode 2)

- For the motorless loudspeaker NES:

Perspectives

- Identification of nonlinear systems (Hammerstein model, Voltera series)
- Adaptation of the methods for a Short Kundt tube with 2 microphones
- Test on other NESs (multiple membrane, microperforated panel)

Experimental set-up and schematic diagram

Excitation mode 1: stepped sines [4]

- $u(t) = A \sin(2\pi f t + \Phi)$
- $f$: signal excitation frequency
- Acquisition of pressure harmonics by demodulation (for each excitation frequency $f$)

Excitation mode 2: synchronized swept sine [5]

- $u(t) = A \sin(\varphi(t))$ with $\varphi(t) = 2\pi f_t t L$
- $[f_1, f_2]$: signal frequency band
- Reconstruction of pressure harmonics: $p(t) = u(t) \ast h(t)$
- Impulse response: $h(t) = \sum_{n=1}^{N} h_n(t + \Delta t)$
- Separation of $N$ harmonics with $\sin(n\varphi(t)) = \sin(\varphi(t + \Delta t))$

Comparison of the frequency responses $H_n(f)$ obtained with excitation modes 1 and 2 for the first 4 harmonics

References