DYNAMICS OF HARMONIC ACTIVE SOUND CONTROL WITH A HARMONIC ACOUSTIC PNEUMATIC SOURCE

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1 Introduction

During takeoff, the harmonic noise of the turbofan is the main acoustic nuisance for people near airports. Much research has been done on the topic of active reduction of turbofan noise [1]. Loudspeakers used as secondary sources present the disadvantage of being fragile and requiring a high power consumption to produce the required sound intensity. In this context, an alternative solution, called the Harmonic Acoustic Pneumatic Source (HAPS), has been designed to generate a high harmonic noise level controllable in amplitude, phase and frequency. Previous studies on the subject have demonstrated the possibility to perform active noise control with a ring of HAPS in a cylindrical duct, but the convergence time of the controller was about several seconds [2]. The dynamics of the controller is thus a limiting factor for active noise control applications. The objective of this study is to address this problem by characterizing and designing a controller with a short response time, typically less than a second. In Sec. 2, the HAPS and its dynamics is presented. Then a controller is designed and simulated in Sec. 3. Finally, the experimental setup for future noise control measurements is presented in Sec. 4.

2 Dynamics of the Harmonic Acoustic Pneumatic Source

2.1 HAPS presentation

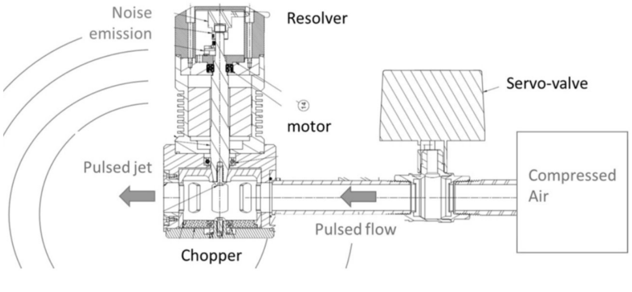

FIGURE 1 – Section view of the acoustic pneumatic source.

The two mechanical components of a HAPS, presented in Fig. 1, are a valve for flow regulation and a flow chopper using a rotating perforated cage. The flow chopper and the valve are equivalent to a variable throat orifice between a plenum of high pressure and the exhaust at the atmospheric pressure [3]. The time variation of the orifice due to the rotation of the chopper generates a pulsed flow. The phase of the pulsed flow is controlled by the rotation angle of the flow chopper. The amplitude of the pulsed flow is controlled by the valve opening. This pulsed flow generates a periodic pressure fluctuation perfectly controlled in amplitude and phase by two signals ($|U|$ and $\angle U$ respectively) in order to physically perform a complex-amplitude modulation of the generated anti-noise. For the following, the complex signal $U(t) = |U(t)|e^{j\angle U(t)}$ is the command for the complex amplitude of the anti-noise first harmonic.

2.2 Dynamics of the HAPS

The HAPS performs a mechanical complex amplitude modulation at a given frequency f_0 controlled by the complex command $U(t)$. However, the time response of the HAPS is not instantaneous, mainly due to the dynamics of the Phase Locked Loop (PLL) algorithm controlling the flow chopper. The PLL is used to synchronize the measured instantaneous angle of the chopper $\theta(t)$ with the reference angle of the anti-noise phase command $\angle U$. An experimental campaign in a semi-anechoic chamber is performed in order to characterize the dynamics of the PLL. A microphone is placed at one meter distance and at an angle of 45° from the HAPS mouth. The reference frequency is $400\,\mathrm{Hz}$. A phase step is used to experimentally evaluate the characteristic time response of the HAPS. The reference phase is initially 0 and jumps to $\frac{\pi}{2}$ at $t = 10\,\mathrm{s}$. The result is shown in Fig. 2. The cage phase is following the reference and the convergence time is $\tau = 0.3\,\mathrm{s}$. Active noise control on a non-stationary primary tone is therefore possible as long as the phase of this primary excitation changes at a slower rate than τ. The signal measured by the microphone indicates a good match with 8 times the phase of the cage, which is a consistent result since there are 8 holes on the cage.

3 Controller design

Knowing the dynamics of the HAPS, a controller is designed. A classical configuration for active noise control experiments including a rectangular duct, a primary loudspeaker, a HAPS and an error microphone, illustrated in Fig. 3, is considered. The unmeasured state of the system is composed of the real and imaginary parts of the acoustic mass flow rate $Q(t)$ at the HAPS mouth. The only measured output is the complex pressure $P(t)$ obtained after demodulation at f_0 of the pressure signal at the microphone $p(t)$. It is the sum of the pressure generated by the HAPS and the perturbation due to the primary source. The dynamics between the command $U(t)$ of the HAPS and the state variable $Q(t)$ is modeled with a first order system with a constant time of $0.3\,\mathrm{s}$, according to the

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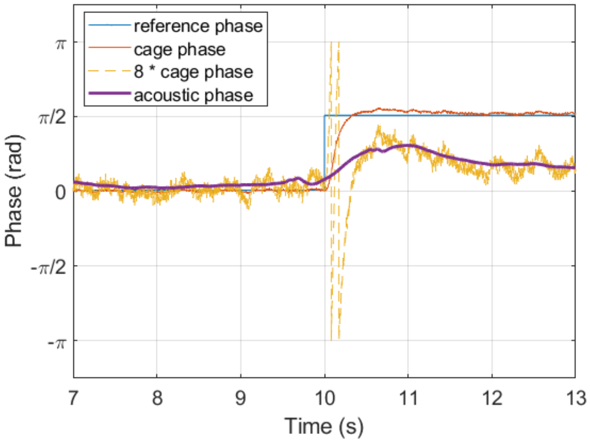

FIGURE 2 – Chopper cage phase and acoustic phase measurement for a step in reference phase.

results about the PLL in Sec. 2.2. The relation between the mass flow rate at the HAPS mouth and the pressure at the microphone is given by the transfer functions extracted from an analytical model of the acoustic propagation in duct. A linear quadratic regulator controller with integral action is designed to minimize the pressure at the microphone. It is complemented with a Kalman observer estimating an augmented state of the system containing the unmeasured state, i.e. the acoustic mass air flow $Q(t)$ and the pressure due to the primary source.

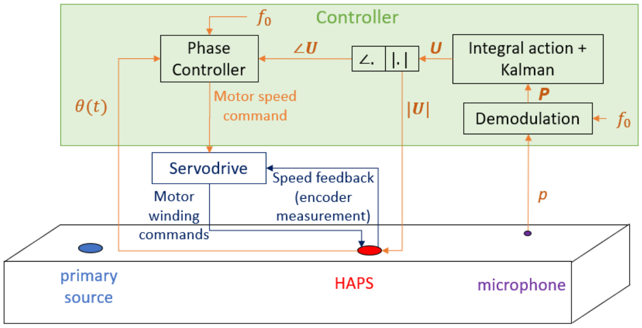

FIGURE 3 – Illustration of the experimental configuration for active noise control.

3.1 Controller simulations

The dynamics of the controller is simulated for a primary sound frequency $f_0 = 300\,\mathrm{Hz}$. The initial state of the system is set to 0, meaning that the HAPS is not activated. The Kalman observer is also initialized at 0, including its estimation of the system state and the primary perturbation. As shown in Fig. 4, the amplitude of the pressure at the microphone is converging to $0\,\mathrm{Pa}$, meaning that the secondary source is canceling the primary sound. An attenuation of $20\,\mathrm{dB}$ is reached in about $1.3\,\mathrm{s}$. The output of the observer is initially zero but it is converging very fast to the system output, in less than $0.03\,\mathrm{s}$, adapting itself to a correct estimation of the primary pressure.

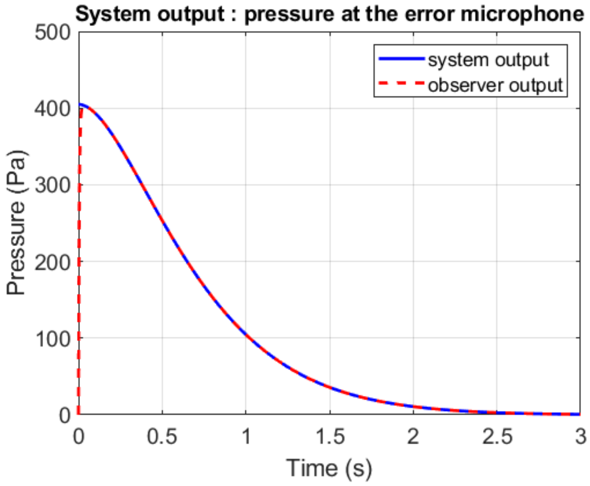

FIGURE 4 – Numerical simulation of the time response of the acoustic pressure modulus $|P|$ at the error microphone. $t = 0$ corresponds to the activation of the secondary source.

4 Noise reduction measurement

In order to validate the control strategy, an experimental setup was designed. It is composed of a duct section with a loudspeaker, a HAPS and a microphone placed on the top side (Fig. 3). It is planned to realize an experimental campaign to perform active noise control. The controller described in Sec. 3 will be implemented using a Speedgoat real-time computer. The measurement of the acoustic attenuation induced by the HAPS at the microphone will be compared to simulations.

5 Conclusions

Measurements of the dynamics of the PLL used to control the flow chopper have been carried out and allowed to measure the characteristic time of the HAPS, $\tau = 0.3\,\mathrm{s}$. Simulations of a controller designed for active noise control in a duct with a HAPS have also been performed. They showed a convergence time of $1.3\,\mathrm{s}$ for the controller. Finally, an experimental setup has been designed in order to validate the control strategy. Future experimental results will provide an accurate estimation of the attenuation achievable with the controller.

Acknowledgments

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