A Module Based Active Noise Control System for Ventilation Systems, Part I: Influence of Measurement Noise on the Performance and Convergence of the Filtered-x LMS Algorithm

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Low noise level is an essential feature when installing ventilation systems today. To achieve attenuation over a broad frequency range, the passive silencers traditionally used to attenuate ventilation noise can be combined with an active noise control (ANC) system. To insure reliable operation and desirable levels of attenuation when applying ANC to duct noise, it is highly important to be able to suppress the contamination of the microphone signals due to the turbulent pressure fluctuations, which arise as the microphones are exposed to the airflow in the duct. This paper is the first in a series of two regarding the problem of turbulence-induced noise originating from the airflow inside the ducts. Part I is concerned with theoretical and experimental investigations of the influence of the turbulence-induced noise on the adaptive algorithm in the ANC system. Part II is concerned with the design and the investigations of microphone installations for turbulence suppression and the results concerning the performance of an ANC system with the different microphone installations are presented. Some of the results were obtained at an acoustic laboratory according to an ISO-standard. The attenuation achieved with ANC was approximately 15-25 dB between 50-315 Hz, even for airflow speeds up to 20 m/s.

1. INTRODUCTION

Low-frequency noise can have negative effects on human well-being, is often annoying, and can also affect our ability to perform different tasks—for example, when working.[1] Ventilation systems constitute a well-known source of low-frequency noise in environments like, schools, factories, hospitals, office buildings etc, as well as in our homes. As awareness of the negative effects of low-frequency noise on human well-being has increased and so too has the requirement for quieter ventilation installations.

A technique which has proven to be an effective way to attenuate low-frequency noise is active noise control (ANC).[2–4] The basic idea of active noise control is to let a secondary source generate a secondary sound field, which destructively interferes with the undesired primary sound field. A single-channel feedforward adaptive control system[2,3] used to attenuate ventilation noise generally consists of two microphones, one loudspeaker, and a control unit. Even though the control unit relies on adaptive digital signal processing, it is of highest importance that the physical arrangement is designed such to insure reliable operation and desirable levels of attenuation.[3,5]

Placing the microphones in airflow will result in noise contamination of the microphone signals, since they will each contain a signal component induced by the turbulent pressure fluctuations, which arise when the diaphragm of the microphones are exposed to the airflow in the duct. A high level of turbulence-induced noise in the reference- and error microphones will lead to a decreased performance of the ANC system.[2,3]

Two papers are presented, which analyze the influence of the turbulence induced noise on the algorithm used in the controller, as well as the design and investigations of different microphone installations for the reduction of the turbulent noise when applying ANC to ducts. In Part I (the present paper), the influence of the turbulent noise on the algorithm is analyzed both theoretically and experimentally. The results show that a high level of turbulent noise present at the reference microphone, as compared to the level of acoustic noise, will affect the optimal filter weight solution and therefore lower the ability of the ANC system to cancel the acoustic noise. It is also shown that measurement noise at the reference sensor will lower the maximum step size and, hence, the maximum convergence rate. Further, the results show that a high level of turbulent noise at the error sensor, as compared to the level of acoustic noise, will not affect the filter weights in mean, but will increase the convergence time of the algorithm. In Part II,[6] different microphone installations for reducing the turbulent noise are investigated. Further, comparative results concerning the performance of an ANC system using the different microphone installations are presented. Some of the results were obtained in an acoustic laboratory according to an ISO-standard.

2. THE ACTIVE NOISE CONTROL SYSTEM

In this work it was desirable to apply ANC in the frequency range up to 400 Hz, which is in the plane-wave propagation region for the ducts used. Hence, a single-channel ANC system could be used instead of a multiple channel ANC system, which would have to be used if ANC was to be applied above the plane wave propagation region.[7,8] The ANC system used was a single-channel feedforward adaptive control system based on the time-domain leaky filtered-x LMS (FxLMS) algorithm[2,3,9] given by Eq. (1),

$$\begin{aligned} y\left(n\right) &= \mathbf{w}^T\left(n\right)\mathbf{x}\left(n\right) \\ e\left(n\right) &= d\left(n\right) + y_F\left(n\right) \\ \mathbf{w}\left(n+1\right) &= \upsilon\mathbf{w}\left(n\right) - 2\mu\mathbf{x}_{\hat{F}}\left(n\right)e\left(n\right), \end{aligned} \tag{1}$$