



EXPERIMENTAL INVESTIGATIONS OF DIFFERENT MICROPHONE INSTALLATIONS FOR ACTIVE NOISE CONTROL IN DUCTS

M. Larsson*, S. Johansson, L. Håkansson and I. Claesson

Department of Signal Processing
Blekinge Institute of Technology
SE-372 25 Ronneby, Sweden

Martin.Larsson@bth.se (e-mail address of lead author)

Abstract

A request on ventilation systems today is the feature of a low noise level. A common method to attenuate ventilation noise is to use passive silencers. However, such silencers are not suitable for the lowest frequencies and one solution is to use active noise control (ANC) to increase the noise attenuation in the low frequency range. Normally when using a feedforward ANC system to attenuate duct noise, both the reference microphone and the error microphone are exposed to airflow. As the airflow excites the diaphragm of the microphones, the microphone signals become contaminated by uncorrelated pressure fluctuations that are not part of the sound propagating in the duct. By reducing the flow velocity around the microphones, these uncorrelated pressure fluctuations can be reduced and the noise reduction improved. One way to reduce the flow velocity around the microphones is to place the microphones in outer microphone boxes connected to the duct via a small slit. In this paper a new practical design for the reduction of flow velocity around the microphones is presented; the microphone installation is based on a T-duct, and therefore it makes maintenance and especially construction easier, compared to the microphone box with a slit. Furthermore, comparative results concerning the performance of an ANC system for the two different microphone installations, the T-duct configurations and the microphone boxes with varying slit width, are presented. The results show that the active noise control performance is almost equal when using the suggested microphone installation as compared to when using a microphone box with a slit.

INTRODUCTION

A low noise level, which contributes to human well-being, is a factor of high importance in schools, factories, office buildings etc, as well as in our homes. In these environments ventilation systems constitute one well known noise source. The classical remedy to noise generated by such systems is passive silencers [1], i.e. dampers containing sound absorbing material. However, because low frequencies have long wavelengths, these passive silencers tend to be relatively large and bulky when used to attenuate noise in the low frequency range. A well known method to attenuate low frequency noise in various situations is active noise control (ANC) [2, 3]. While ANC is best suited for low frequencies, passive silencers are best suited for higher frequencies and therefore a combination of the two often is an attractive solution.

A single-channel feedforward adaptive control system used to attenuate ventilation noise generally consists of two microphones, one loudspeaker and a control unit. One microphone –a reference microphone– is placed upstream relative the loudspeaker. The reference microphone detects the noise propagating in the duct and generates a reference signal which is fed to the control unit that steers the loudspeaker. Downstream from the loudspeaker, the other microphone –an error microphone– is placed. The error microphone senses the residual noise after control and generates an error signal which is also fed to the controller. The reference- and error signals allow the controller to adjust itself to continuously minimize the acoustic noise sensed by the error microphone. It does this by creating an output via the loudspeaker that is based on the reference signal and out of phase with the sound propagating in the duct by the time it reaches the placement of the error microphone.

A continuous problem when applying ANC to duct noise is the airflow present in the ducts that the microphones are exposed to. Placing the microphones in airflow will result in contamination of the microphone signals, since they will contain a contribution of turbulence pressure fluctuations arising when the airflow excites the diaphragm of the microphones. A high level of turbulence compared to the level of noise propagating in duct will lead to less correlation between the reference- and error signals. This in turn results in a decreased performance of the ANC system [2, 3]. Therefore it is essential to reduce the amount of uncorrelated turbulence fluctuations which not are a part of the propagating sound, to optimize the noise attenuation potential of the active control system. A common way to do so is by placing the microphones in outer turbulence boxes connected to the duct via a small slit [3, 4]. As shown in [4] the performance of an ANC system applied to duct noise can be significantly improved by placing the reference- and error microphones in outer microphone boxes. However, such microphone boxes implies a new construction of the duct pieces in which the microphones are placed. In this paper a microphone installation based on a standard T-duct is presented. Since the microphone installation is based on a duct piece already manufactured, eliminating the need for the development of new

duct pieces, this of course makes it an attractive solution to manufacturers of ventilation systems. Furthermore, comparative results concerning the performance of an ANC system with different microphone installations; T-duct configurations and microphone boxes with varying slit width are presented. The results show that the active noise control performance is almost equal or better when using the suggested T-duct based microphone installation as compared to when using a microphone box with a slit.

THE EXPERIMENTAL SETUP

The measurements were carried out in a laboratory at Lindab AB in Farum, Denmark and on a duct system built in a laboratory at Blekinge Institute of Technology (BTH), Sweden. The duct system used at BTH was circular with a length of approximately 21 meters and a diameter of 315 mm. The system was equipped with a standard axial fan (Lindab CK315), a passive silencer (Lindab SLU 100) and a draught valve close to the fan to regulate the airflow. In these measurements two different airflows were used; 3,2 m/s with the draught valve closed and 6,7 m/s with the draught valve completely open. The passive silencer, the loudspeaker and the error microphone were located near the duct outlet. The attenuation was evaluated in the error microphone. Figure 1 is a diagrammatic illustration of the experimental setup at BTH which henceforth will be referred to as *setup1*. The laboratory at Lindab AB had the possibility

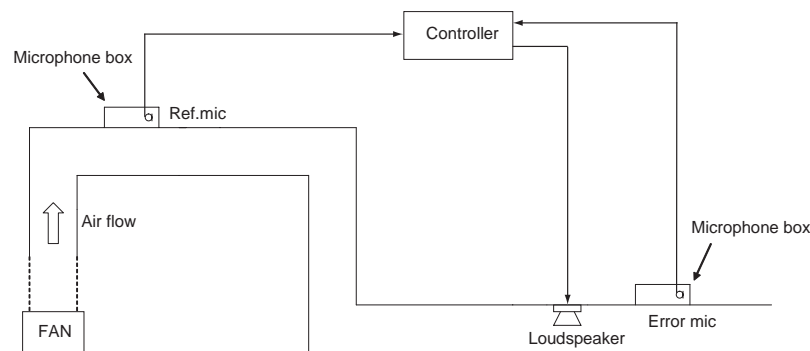


Figure 1: The experimental setup at Blekinge Institute of Technology, *setup1*.

to measure according to the standard ISO 7235:2003 - "Acoustics - Laboratory measurement procedures for ducted silencers and air-terminal units - Insertion loss, flow noise and total pressure loss". Figure 2 is a diagrammatic illustration of the experimental setup in the laboratory at Lindab AB which henceforth will be referred to as *setup2*. The airflow generated by the fan was led up via large passive silencers, attenuating all acoustic noise generated by the fan, to the room to the left in figure 2, in which a loudspeaker array for noise generation was positioned. The room to the

right in figure 2 is a reverberation room in which the attenuation was measured using a microphone placed in the position denoted *Evaluation mic* in figure 2. Between the rooms were approximately 20 meters of duct having a diameter of 315 mm and in the middle the active system was installed. This set-up made it possible to generate a variety of airflow speeds without noise generation, noise generation without airflow and also to generate airflow and noise together.

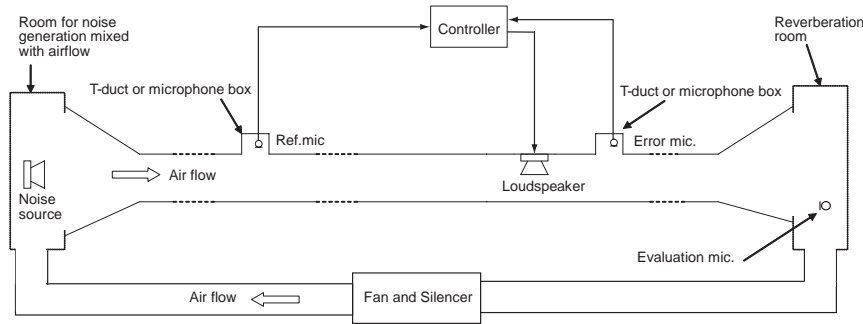


Figure 2: The experimental setup at Lindab AB, setup2.

The active control system used in both experimental setup:s comprised one loudspeaker, one reference microphone, one error microphone and a control unit. The controller was based on the time-domain leaky filtered-x LMS algorithm [3]. The control filter consisted of 256 coefficients and the control path, the path between the loudspeaker input and the error microphone output, was estimated with an FIR-filter with 128 coefficients, using the LMS algorithm. The control path was estimated before active control, i.e. off-line system estimation[3].

The Microphone Arrangements

Two different types of microphone installations were designed and evaluated: microphone boxes and T-ducts.

Microphone Boxes

The principle of the microphone box is similar to the principle of the probe tube investigated by among others Neise [5], although it has been shown that the microphone box will further reduce the influence of turbulent pressure fluctuations [3]. The microphone boxes used are described in [4] and illustrated in figure 3. To investigate if the width of the slit affected the performance of the active control system, microphone boxes having slit widths of 3, 6 and 9 mm were built.

T-ducts

The microphone installations based on T-ducts are illustrated in figure 4. These were constructed using regular T-ducts manufactured by Lindab AB. The vertical duct

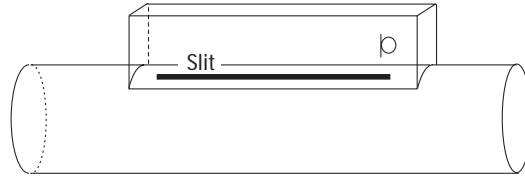


Figure 3: Schematic illustration of the microphone box.

piece has a diameter of 160 mm and a height of 50 mm. On top there was a tightly closing cover clamped and the cavity was filled with porous plastic foam for further turbulence rejection. In the transition between the horizontal and vertical duct pieces there was a net riveted to prevent the porous material in the cavity from falling out. Even though this net will cause turbulence, the T-ducts, as shown in figure 8, has a better turbulence rejection than the microphone box with a 400 mm long and 9 mm wide slit.

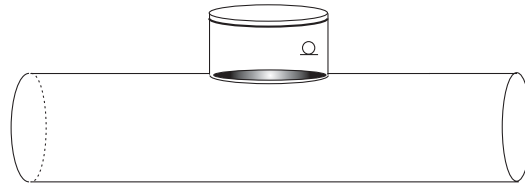


Figure 4: Schematic illustration of the T-duct installation.

EXPERIMENTAL RESULTS

The measurements presented were, for both experimental setup:s, carried out in the frequency range of 0-400 Hz which is well below the cut-on frequency for the first higher order mode of the ducts in use. In *setup1* the reference- and error microphones were mounted in microphone boxes having a slit length of 400 mm and slit widths of 3, 6 and 9 mm. The airflow was either 3,2 m/s or 6,7 m/s. The microphones were placed in the positions denoted *Ref.mic* and *Error mic* in figure 1. The attenuation at the error microphone with active control, using microphone boxes with the different slit widths, for airflows of 3,2 m/s and 6,7 m/s is illustrated in figure 5.

In *setup2* the performance of the active control system was evaluated with the reference- and error microphones mounted in T-duct installations and in microphone boxes having a slit width of 9 mm. Only the microphone boxes having a slit width of 9 mm were used in *setup2* since they resulted in the highest attenuation in *setup1*. In both cases—the microphones mounted in T-duct installations as well as in microphone boxes—the microphones were placed in the positions denoted *Ref.mic* and *Error mic* in figure 2. When T-ducts were used the airflow was regulated from 0 m/s, i.e only noise generated from the loudspeaker array was present, up to 20 m/s. When the microphone boxes were used the airflows used were 0 m/s and 10 m/s. The attenuation

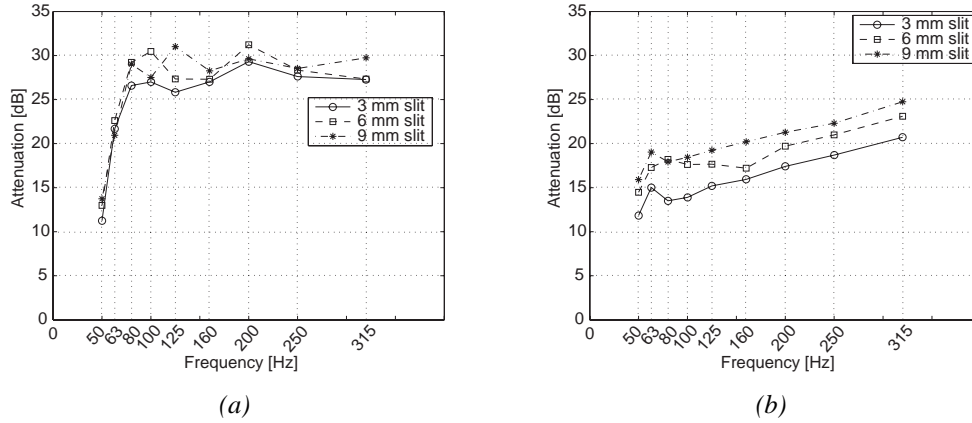


Figure 5: 1/3 octave spectrum of the attenuation at the error microphone with active control in setup1. Error- and reference microphones placed in microphone boxes with 400 mm long and (circles) 3mm wide slit, (squares) 6mm wide slit and (stars) 9mm wide slit. (a) for an airflow of 3,2 m/s and (b) for an airflow of 6,7 m/s.

at the evaluation microphone in the reverberation room with active control when the reference- and error microphones were mounted in T-duct installations is illustrated in figure 6.

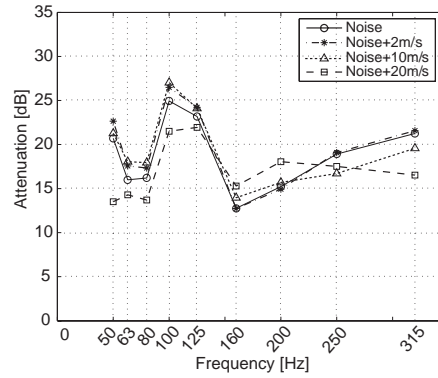


Figure 6: 1/3 octave spectrum of the attenuation at the evaluation microphone with active control for (circles) noise only, (stars) noise plus an airflow of 2 m/s, (triangles) noise plus an airflow of 10 m/s and (squares) noise plus an airflow of 20 m/s. Error- and reference microphones mounted in T-duct installations in setup2.

The attenuation at the evaluation microphone in the reverberation room with active control when the reference- and error microphones were mounted in T-duct installations and in microphone boxes is illustrated in figure 7.

The power spectral density (PSD) of the noise generated at a microphone when it was mounted inside the duct without any windscreen, inside a microphone box with

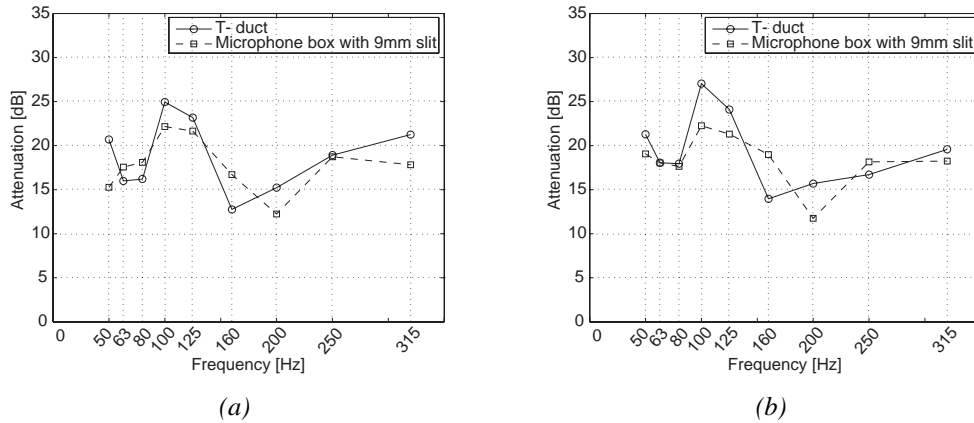


Figure 7: 1/3 octave spectrum of the attenuation at the evaluation microphone with active control in setup2 using (circles) T-duct installations and (squares) microphone boxes with a 9 mm wide slit.(a) noise only and (b) noise plus an airflow of 10 m/s.

a slit width of 9 mm and inside a T-duct installation, was measured and is illustrated in figure 8, when only airflow was generated in the duct. This gives a good measure of the turbulence rejection achieved by the different microphone installations, since the acoustic noise generated by the fan is silenced which otherwise would mask the actual amount of turbulence rejection.

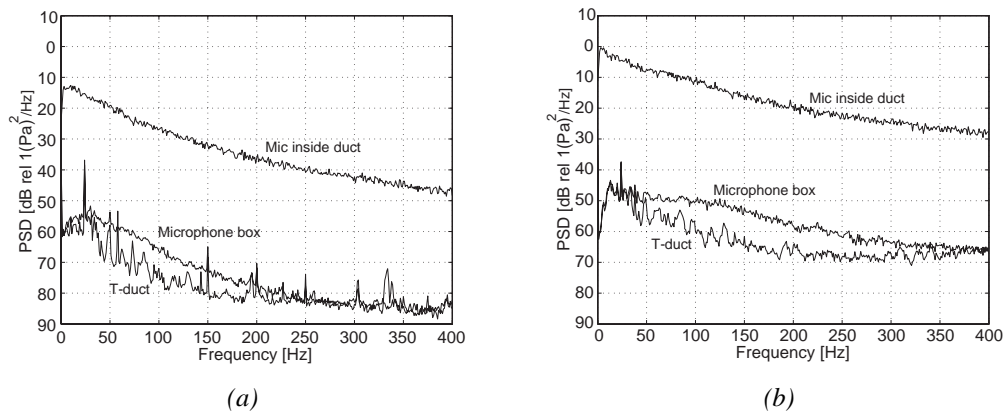


Figure 8: Power spectral density (PSD) of the turbulent noise when only airflow was generated (dashed line) with the microphone placed inside the duct, (solid line) with the microphone placed inside a T-duct installation and (dash-dotted line) with the microphone placed inside a microphone box with 400 mm long and 9 mm wide slit. (a) for an airflow of 3 m/s and (b) for an airflow of 6 m/s.

SUMMARY

The slit width of the microphone boxes made no significant difference in noise attenuation for the airflow 3,2 m/s (see figure 5). For the airflow 6,7 m/s however, the

attenuation between 50 Hz and 315 Hz was approximately 5 dB higher when using the slit width 9 mm as compared to the slit width 3 mm (see figure 5). With the microphones mounted in T-duct installations the attenuation was approximately the same when no airflow was present as when airflow was present, even up to airflow speeds of 20 m/s (see figure 6). The comparison between microphone boxes with 9 mm wide slit and the T-duct installations show, both for an airflow of 0 m/s and 10 m/s, that the attenuation is approximately the same, or even increased using T-ducts, except for the 160 Hz band (see figure 7). Furthermore, the turbulence rejection using a T-duct installation compared to when using a microphone box with a 9 mm wide slit, is approximately 5 dB higher between 50- and 200 Hz for an airflow of 3 m/s (see figure 8). For an airflow of 6 m/s the turbulence rejection is approximately 5-10 dB higher (depending on the frequency) between 50- and 300 Hz with the T-duct installation compared to the microphone box with a 9 mm wide slit (see figure 8). Finally, placing the microphones in outer turbulence boxes increases the turbulence rejection and thereby the attenuation achieved from the active control system. The T-duct installations further increase the turbulence rejection and also the achievable attenuation from the active system as compared to the microphone boxes with a slit. Since the T-ducts also make the construction easier these are an attractive and recommended type of microphone installation.

ACKNOWLEDGEMENT

The authors wish to thank the KK-foundation for its financial support. They also wish to express their gratitude to Lindab AB for all support and practical help with the experimental setup of the ventilation system and with the measurements at the laboratory in Farum, Denmark.

References

- [1] Leo L. Beranek. *Noise And Vibration Control*. McGraw Hill, Inc., 1988.
- [2] Colin H.Hansen and Scott D.Snyder. *Active Control of Noise and Vibration*. E & FN Spon, 1997.
- [3] Sen M. Kuo and Dennis R. Morgan. *Active Noise Control Systems*. John Wiley & Sons, Inc., 1996.
- [4] M. Larsson et. al. Microphone windscreens for turbulent noise suppression when applying active noise control to ducts. In *Twelfth International Congress on Sound and Vibration*. IIAV, 2005.
- [5] W. Neise. Theoretical and experimental investigations of microphone probes for sound measurements in turbulent flow. *Journal of Sound and Vibration*, 39(3):371–400, 1975.