MICROPHONE WINDSCREENS FOR TURBULENT NOISE SUPPRESSION WHEN APPLYING ACTIVE NOISE CONTROL TO DUCTS

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Abstract

Low noise level is an essential feature when installing ventilation systems today. Traditional noise control approaches use passive silencers to attenuate ventilation noise. Such silencers are rather ineffective at low frequencies and tend to be relatively large and bulky when used in the low frequency range. One method to improve the low frequency noise attenuation and reduce the size of low frequency silencers is active noise control (ANC). One problem when applying this approach to ducts is that both the reference microphone and error microphone are placed in an airflow. As a result, the microphones sense the sound propagating through the duct as well as the turbulent pressure fluctuations generated by the airflow around the microphones. The turbulent flow noise reduces the coherence between the reference microphone and the error microphone, resulting in reduced performance by a feedforward ANC system. This paper presents comparative results from microphone installations based on different windscreens for reducing turbulent wind noise in the microphones.

INTRODUCTION

The classical approach of attenuating noise in ventilation systems is passive silencers [1]. In the low frequency range the passive silencers tend to be relatively
large, bulky and impractical. A well-known method for attenuating low-frequency noise is active noise control (ANC) \[2\,3\]. The configuration of a feedforward adaptive control system comprises a loudspeaker and two microphones. An upstream microphone –reference microphone– detects the noise propagating in the duct and generates a reference signal which is fed to a control unit that steers a downstream loudspeaker. Downstream from the loudspeaker an error microphone monitors the residual noise after control and allows the controller to adjust itself to continuously minimise the acoustic noise sensed by the error microphone. This causes the loudspeaker to generate a sound field which is out-of-phase with the propagating duct noise at the error microphone and in this way attenuates the propagating duct noise. Applying ANC to duct noise normally involves placing microphones in airflow. The microphones sense both the turbulent pressure fluctuations excited by the flow at the microphone as well as sound propagating down the duct. The attenuation of the propagating sound is related to the coherence between the reference and error microphone signals \[2\,3\]. A simple estimate of the reduction in noise achieved by an ANC system is given by $-10 \log_{10}[1 - \gamma_{dx}(f)^2] \text{dB}$, where $\gamma_{dx}(f)$ is the coherence function between the reference signal and the error microphone signal in the absence of control \[2\,3\]. The turbulent pressure fluctuations contaminate the microphone signals, reduce the coherence and limit the achievable noise reduction. It has been shown in \[4\] that the level of turbulence noise is a threshold value below which active attenuation is ineffective. Accordingly, to utilise the noise attenuation potential of the active control system, it is essential to reduce any uncorrelated turbulence pressure fluctuations which not are a part of the propagating sound. Many different approaches to do so have been described over the years.

The work of Åbom and Schiegg \[5\] describes the use of a hot wire that measures the fluctuating velocities which is then used as a reference signal for the turbulence. Another method is to use a microphone array \[2\] consisting of a number of microphones arranged in a line directed towards the noise source. The signal from each microphone in the array is delayed electronically with the acoustic propagation time from the actual microphone to the microphone furthest from the noise source and subsequently linearly combined. This, in turn, result in a suppressed turbulent pressure signal component in the array output signal. A much more practical and less expensive method is the use of probe tube microphones described in \[2\]. By placing a microphone in an airflow, turbulence fluctuations are generated \[5\]. The turbulence fluctuations will be somewhat reduced due to the streamlined shape of the probe tube. However, if the microphones are placed in outer turbulence boxes connected to the duct through a small slit, the turbulence fluctuations will be further removed and the coherence will be improved \[3\].

**THE EXPERIMENTAL SET-UP**

The measurements were carried out on a circular duct system equipped with a standard axial fan (Lindab CK 315), a passive silencer (Lindab SLU 100) and
a draught valve close to the fan to regulate the airflow. With a closed draught valve the airflow was 2.8 m/s and with completely open draught valve it was 5.9 m/s. The length of the duct was approximately 21 meters and the diameter was 315 mm. The passive silencer, the loudspeaker and the error microphone were located in the vicinity of the duct outlet. Figure [1] is a diagrammatic illustration of the experimental set-up. The microphones were located in two possible positions: one inside the duct and one in a microphone-box mounted on the duct. The evaluation position was in the room in front of the duct outlet. A foam plastic sleeve was used as windscreen. The controller was based on the time-domain leaky filtered-x least mean squares algorithm with a normalised step size [3]. The control filter consisted of 256 coefficients and the control path, the path between the loudspeaker input and error microphone output, was estimated with a FIR-filter of 128 coefficients. Two different types of microphone screens were designed: probe tubes and microphone boxes. However, for reference purposes the performance of the active system was also verified with standard foam plastic sleeves as windscreens and without any windscreens at all.

![Figure 1: The experimental set-up](image)

**Foam Plastic Sleeves:** Common windscreens placed for example on microphones in public address systems and acoustic measurement systems are usually based on foam plastic sleeves. With the windscreen, the airflow also generates noise, but the turbulence is located away from the microphone so that the noise is attenuated by the time it reaches the diaphragm [1]. Turbulence is attenuated more effectively by increasing the thickness of the foam plastic. On the other hand, the turbulent noise attenuation is negatively influenced by increased airflow speed [1]. The foam plastic sleeves used were spherical with a diameter of 9 cm. In this set-up the microphones were mounted on a cross sectional bar centered in the duct as described in figure [2]. However, turbulence and noise can be generated downstream of the microphone when the microphone supports are exposed to airflow. Accordingly, microphones should be installed where the airflow is low,
e.g. in a box attached to the duct exterior and connected to the duct interior via a slit etc. A microphone picks up the acoustical signal but is less affected by the airflow.

![Microphone mounted in the duct with a foam plastic sleeve as windscreen.](image)

**Figure 2: Microphone mounted in the duct with a foam plastic sleeve as windscreen.**

**Probe Tubes:** The probe tube usually consists of a tube plugged at both ends, and along the tube there is a slit. The microphone is mounted inside the tube at the downstream end. The principle of the probe tube is that the sound wave and the airflow generating the turbulent noise travel at different speeds [2]. The propagating sound entering the tube through the slit will tend to increase itself via additions of sound from the outside as it travels along the tube. The airflow outside the tube will not travel as fast as the turbulent noise inside the tube; the turbulent noise entering at one point in the tube will not be related to the turbulent noise at another point. This results in reduced turbulent noise. Two probe tubes were designed and are shown in figure 3. These were constructed using regular cigar tubes with a length of 162 mm and diameter of 19 mm. The slit length and width are 135 mm and 1,5 mm respectively. The probe tube diameter should be less than 0,1 of the duct diameter [2]. Since the duct diameter in the experimental set-up is 315 mm and the tube diameter is 19 mm this criteria is fulfilled. The cut-off frequency, $f_c$, below which turbulent pressure fluctuations will not be attenuated is given by $f_c = c_0 M/[L(1 - M)]$, where $L$ is the probe tube length and $M = U/c_0$ is the flow Mach number [2]. Here, $U$ is the mean flow speed in the duct and $c_0$ is the speed of sound. Using the equation for $f_c$ with the current probe tube length, the cut-off frequency for the flow 2,8 m/s is $f_c \approx 17$ Hz; for the flow 5,9 m/s, $f_c \approx 37$ Hz. To optimize the performance of the probe tube microphone, it is necessary to cover the slit with acoustically porous cloth, which minimizes the damping effect of the slit on the acoustic waves propagating in the tube [2]. Therefore, when the tubes were placed in the duct the slit was covered with plastic foam as shown in figure 3(b).

**Microphone Boxes:** The microphone boxes were made of 12 mm chipboard. These were mounted on the outside of the duct. A 5 mm wide slit was made between the cavity and the duct interior. The microphone box design is illustrated in figure 4 and based on the work of Wang and Crocker [6]. When designing slit tubes, a longer tube may have more turbulence eddies averaged over the tube, therefore it may have higher turbulence rejection. However, a tube with a length of 400 mm is considered to be sufficiently long to produce adequate turbulence rejection at about 10-15 dB [6]. Therefore, one of the boxes was made 400 mm
long. The length of the other box was 800 mm. The increased length however did not result in any further improvement; the longer box was thus sealed inside to give it an overall length of 400 mm.

![Probe Tube](image1)

![Figure 3](image2)

Figure 3: The probe tube in (a) with the slit visible and in (b) mounted on the wall inside the duct.

![Microphone Box](image3)

![Figure 4](image4)

Figure 4: The microphone box in (a) closed and in (b) open with the slit visible

**EXPERIMENTAL RESULTS**

The measurements presented were carried out in the frequency range of 0-400 Hz – the plane wave propagation region for the ducts in use – and for airflow speeds of up to 5.9 m/s. When the microphones had no windscreens they were placed in the positions denoted `ref.mic 1` and `error mic 1` in figure 1. The power spectral density (PSD) of the sound measured using the room microphone, for an airflow of 2.8 m/s is illustrated in figure 5. The dashed line shows the result when the ANC system is off and the solid line shows the result when the ANC system is on. When the airflow was increased to 5.9 m/s it was impossible to make the ANC system stable. Microphones fitted with foam plastic sleeves as windscreens were placed in the positions denoted `ref.mic 1` and `error mic 1` in figure 1. The total sound pressure level is higher for the airflow 2.8 m/s because the airflow is then regulated with a draught valve which leads to a higher sound pressure level generated by the fan. The PSD of the sound measured using the room microphone for airflows of 2.8 m/s and 5.9 m/s, is illustrated in figure 6.
Figure 5: Power spectral density of the sound measured at the room microphone (dashed line) without and (solid line) with active control; without windscreens and for an airflow of 2.8 m/s.

Microphones fitted with probe tubes as windscreens were placed in the positions denoted ref.mic 1 and error mic 1 in figure 1. The results are illustrated in figure 7. When microphone boxes were used, the microphones were placed in the positions denoted ref.mic 2 and error mic 2 in figure 1. Inside the boxes the microphones had two different types of windscreens: foam plastic sleeves and probe tubes. The results are illustrated in figure 8.

Figure 6: Power spectral density of the sound measured at the room microphone (dashed line) without and (solid line) with active control; foam plastic sleeves as windscreens. (a) airflow 2.8 m/s and (b) airflow 5.9 m/s.

SUMMARY

Windscreens improve the noise attenuation significantly. Standard foam plastic sleeves increase attenuation by approximately 10 dB and enlarge the range of attenuation at low frequencies by about 50 Hz as compared with when no screens
Figure 7: Power spectral density of the sound measured at the room microphone (dashed line) without and (solid line) with active control; probe tubes as windscreens. (a) airflow 2.8 m/s and (b) airflow 5.9 m/s.

were used for an airflow of 2.8 m/s. Foam plastic sleeves also makes the ANC system stable for an airflow of 5.9 m/s. Probe tubes further increase the range of attenuation up to 400 Hz, the attenuation however remains approximately the same as when foam plastic sleeves are used when the airflow is 2.8 m/s. When the airflow is 5.9 m/s the performance is slightly reduced. By increasing the thickness of the plastic foam covering the slit, high airflow performance should improve. Placing the microphones in boxes outside the duct with foam plastic sleeves as windscreens further increases the attenuation between 250-400 Hz with about 5-10 dB when the airflow is 2.8 m/s. With an airflow of 5.9 m/s the attenuation is increased by 5-10 dB and the range of attenuation is enlarged up to 400 Hz. Probe tubes inside the microphone boxes result in smoother attenuation. The attenuation is also slightly increased between 150 and 400 Hz with an airflow of 2.8 m/s. With an airflow of 5.9 m/s attenuation and the range of attenuation remain approximately the same. The reduced performance with an airflow of 5.9 m/s exhibited by all the different screens, is probably the result of the high level of turbulence pressure fluctuations as well as the reduced level of acoustic noise propagating through the duct. This in turn reduces the coherence between the reference and error microphone signals. Finally, using windscreens together with microphone boxes increases noise attenuation significantly.

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Figure 8: Power spectral density of the sound measured at the room microphone (dashed line) without and (solid line) with active control. (a) airflow 2.8 m/s and (b) airflow 5.9 m/s, both with foam plastic sleeves inside the microphone boxes. (c) airflow 2.8 m/s and (d) airflow 5.9 m/s, both with probe tubes inside the microphone boxes.

REFERENCES


