EXPERIMENTS ON PERFORMANCES OF ACTIVE-PASSIVE HYBRID MUFFLERS

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A kind of active-passive hybrid muffler is developed for ventilation systems to reduce broadband noise. Performances of active noise control (ANC) are related to parameters of controller and configurations of muffler and pipe. In this work, an experimental system is implemented to investigate the influence of these parameters. A loud speaker and a centrifugal fan are used as noise sources for the cases without air flow and with air flow, respectively. For the case without air flow, effects of analog low-pass filters in the controller, locations of sensors in mufflers and structures of pipe end on ANC performances are studied. In addition, noise reductions inside and outside the pipes are compared. For the case with air flow, passive and active-passive performances of an active-passive hybrid muffler with optimized parameters are analyzed.

1. Introduction

Passive mufflers are commonly installed in ventilation systems to reduce the noise generated by the fans, compressors and turbulences, which are effective for high frequency noise above several hundred Hertz. However in the low frequency range passive mufflers tend to be relatively large, bulky and impractical [1-2]. An effective way of reducing low frequency noise is active noise control (ANC). In an ANC system, a secondary source is used to generate an anti-noise for cancelling the primary noise source based on the principle of superposition. The application of ANC in ventilation systems has been widely investigated since only one-dimensional ducts or pipe network are involved. The advantage of ANC over passive mufflers is superior low-frequency attenuation with negligible flow restriction. In addition, active mufflers based on ANC are lightweight and compact.

An active muffler involves algorithms, controllers, amplifiers, loudspeakers and sensors all of which must have excellent performances and be incorporated well for achieving a good reduction of noise. A large part of work on ANC is focused on algorithms. In many kinds of algorithms, the filtered-x least mean square (FxLMS) algorithm is a good choice for ANC applications [3]. A general discussion of the practical system considerations for ANC in the duct-acoustic problem has been given by Kuo and Morgan [1], which involves sampling rate, filter length, coherence, causality and so on. Chan et al. [4] investigated the influence of secondary loudspeaker parameters on the performance of feed-forward active duct noise control. Recently several methods were proposed to suppress the turbulence-induced local pressure fluctuations for enhancing ANC performance [5-6].

Although there is still much work on active mufflers, active muffler products are very few until now since their cost and complexity are high. In addition, active mufflers have limited performances at higher frequencies and must be combined with passive mufflers in order to reduce broadband noise.

In this work, practical system considerations of active mufflers are investigated further by experiments and a kind of active-passive hybrid muffler is developed. Performances of active mufflers are related to parameters of controller and configurations of muffler and pipe. The influence of these parameters is studied in an experimental system where a loud speaker and a centrifugal fan are used as noise sources for the cases without air flow and with air flow, respectively. For the case without air flow, effects of analogue low-pass filters in the controller, locations of sensors in mufflers and structures of pipe end on ANC performances are studied. In addition, noise reductions inside and outside the pipes are compared. For the case with air flow, passive and active-passive performances of an active-passive hybrid muffler with optimized parameters are analyzed.

2. Experimental setup

The experimental setup is implemented in a sound insulation testing room as shown in Fig.1. It consists of two parts. One part includes a loud speaker and a centrifugal fan which are placed in the source room and used as noise sources. The other part includes two passive mufflers and one active muffler. The active muffler is between the two passive mufflers. The two parts are arranged at the two ends of a pipe with 100mm diameter and their outsides are separated by a thick plate in order to suppress the sound transmission outside the pipe. The active muffler consists of an error microphone, a secondary loudspeaker and its amplifier. The reference microphone inside passive muffler 1 provides reference signal for the active muffler and its distance from the active muffler can be changed by adding different straight pipes. A monitoring microphone is outside the outlet of the pipe and used for evaluating the noise reduction performance. The loudspeaker and centrifugal fan can generate primary noise independently or at the same time. The wind speed inside the pipe varies over 0-15 m/s when the centrifugal fan works.

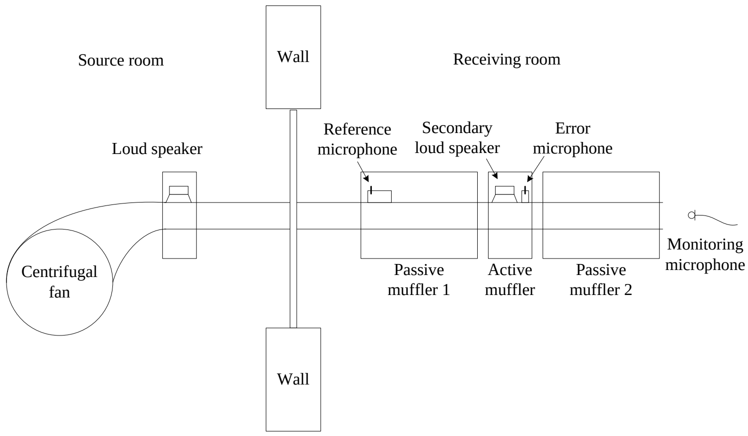


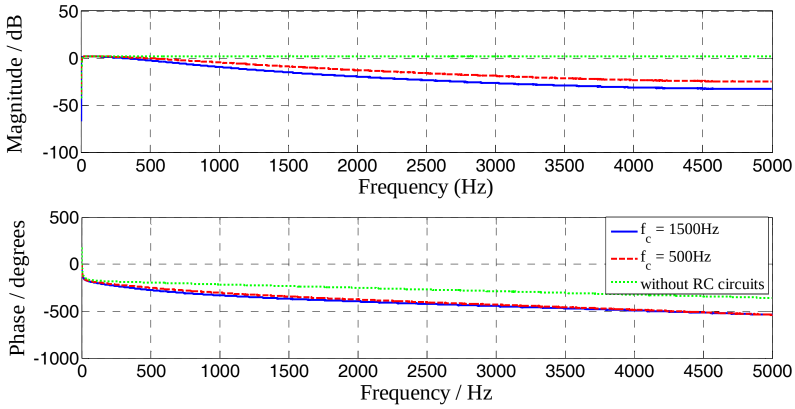
Figure 1. Experimental setup.

3. Experimental results

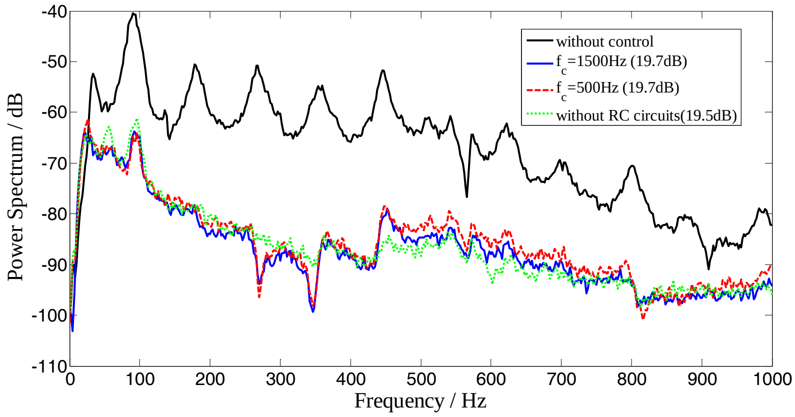
Two kinds of experiments are carried out at the experimental setup illustrated in Fig. 1. At first effects of parameters of controller and configurations of muffler and pipe on performances of the active muffler are studied. These parameters include analogue low-pass filters in the controller, locations of sensors in mufflers and structures of pipe end. In addition, noise reductions inside and outside the pipes are compared. Then an active-passive hybrid muffler with optimized parameters is developed and its passive and active-passive performances are analyzed.

3.1 Effects of parameters of controller, muffler and pipe on ANC performances

Low-pass anti-aliasing and reconstruction filters are necessary in DSP systems. However, the delay of these filters would affect the causality of ANC systems and hence attenuate the performance. Here 1st order resistor-capacitor (RC) circuits are used to minimize this delay. Figure 2(a) shows responses of RC circuits with different cut-off frequencies f_c and Figure 2(b) shows the control performances with these low-pass filters. The responses shown in Figure 2(b) contain two RC circuits as well as the inherent 1-point delay of the DSP system. It could be seen that with different low-pass filters the control performances are almost the same. This results means that the low-pass filter delay has little affection on the causality of the ANC system. Finally RC circuits with 1500Hz cut-off frequency are used in the muffler.



(a) Resposes of different low-pass filters and the DSP delay



(b) Control performances

Figure 2. Control performances with different low-pass filters

In an ANC system, causality is a key issue for the control performance. It requires that the propagation delay between the reference microphone and the loudspeaker must be greater than the delay of the DSP system. In the muffler, the distance between the reference microphone and the loudspeaker is about 40cm, and the sampling frequency is 10k Hz. Simulations are carried out with different extra propagation delays using recorded reference and error signals, and the results are shown in Figure 3. It can be seen that with a larger delay, which means that the reference microphone is more away from the loudspeaker, a better performance would be obtained. However, no apparent performance enhancement could be obtained if the delay is less than 20-point (about 70cm). Considering the size of the muffler could not be very large, the 40cm distance between the reference microphone and the loudspeaker might be good enough.

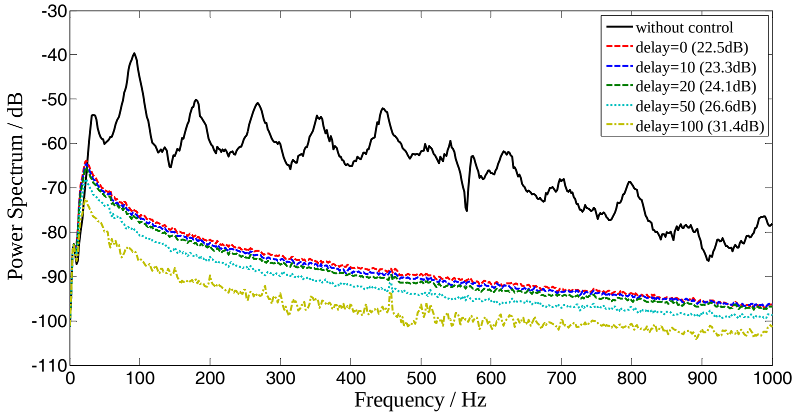
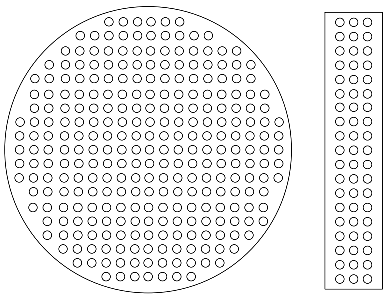
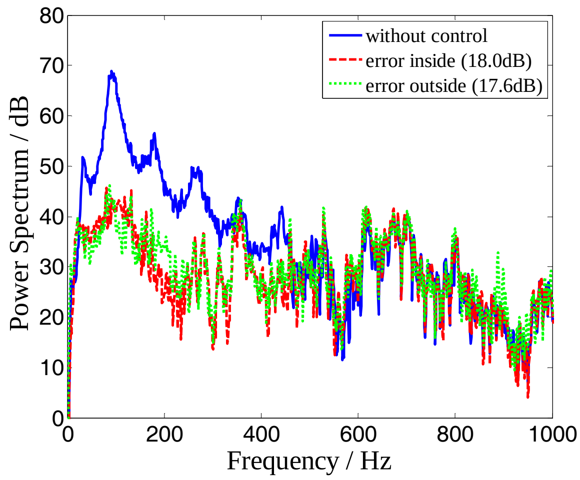


Figure 3. Predicted control performances with different delays of primary path

Figure 4 shows the control performances with different error microphones which locate inside and outside the duct, respectively. Figure 4(a) gives the relative position between the loudspeaker and the error microphone inside the duct, from which it can be seen that the error microphone is placed close to the loudspeaker. A rectangular structure similar to the microphone box with a slit in [6] is used to suppress the turbulence-induced local pressure fluctuations. Meanwhile, since the muffler is attached at the end of the duct, the error microphone inside the duct is also close to the outlet of the duct. Figure 4(b) compares the experimental control performances with error microphones inside and outside the duct, which are almost the same. This result indicates that when the muffler is attached at the end of the duct, using an error microphone which is placed inside the duct and close to the loudspeaker is good enough to control the noise radiated from the outlet of the duct.



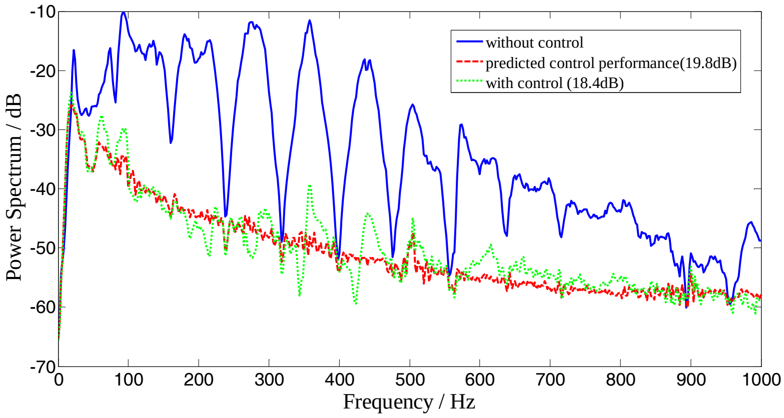
(a) Relative position between loudspeaker and error microphone



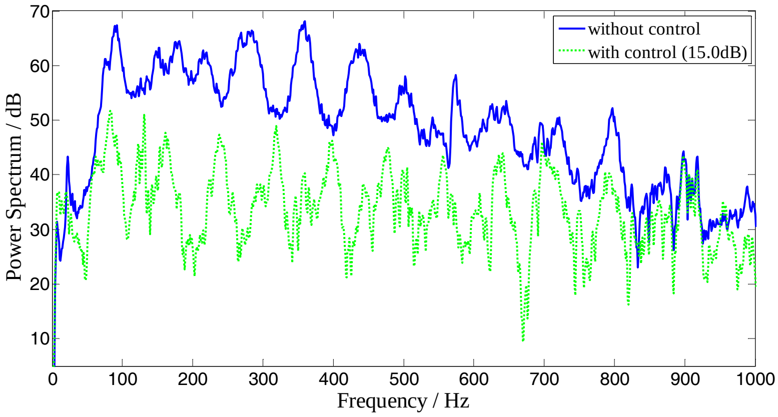
(b) Control performances with error microphones inside and outside the duct

Figure 4. Control performances with different error microphones

However, if the muffler is attached at the middle of the duct, which means a relative long duct between the error microphone and the duct's outlet, things are different. Figure 5 shows the experimental control performances when a 3m long duct is attached at the end of the muffler. Although the noise at the error microphone could be reduced by 18.4 dB, the noise radiated from the duct's outlet is only reduced by 15.0 dB. This 3 dB loss of the performance is mainly caused by the stand waves of the duct, which makes the peaks and notches more apparent inside the duct than the outside. With an inside error microphone, although the peaks could be reduced a lot, little reductions are achieved at the notch frequencies. This makes a non-flattened residual noise and hence the performance has a 3 dB loss.



(a) Control performance at the error microphone

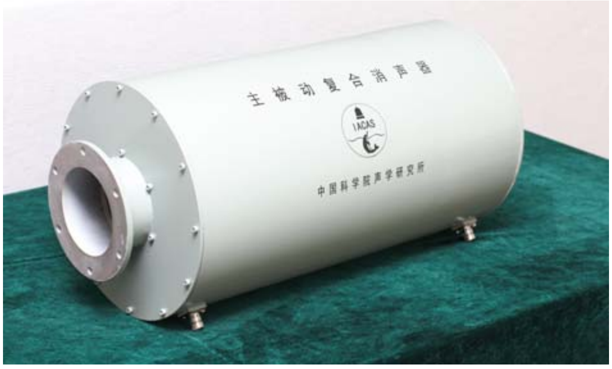


(b) Control performance at the outlet

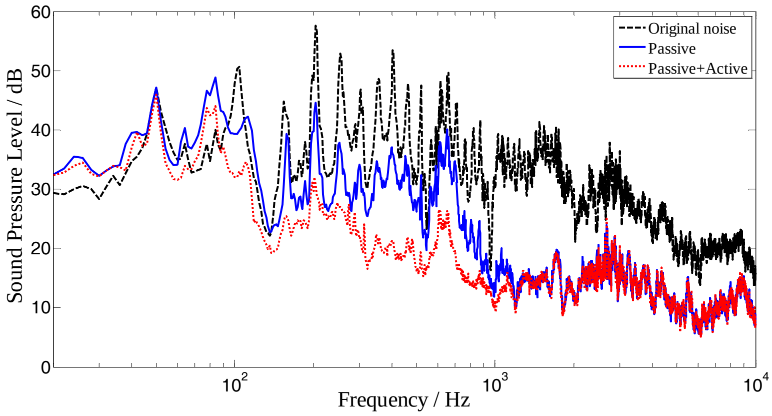
Figure 5. Control performance with a 3m long duct attached at the end of the muffler

3.2 Performance of an active-passive hybrid muffler

A kind of active-passive hybrid muffler with optimized parameters is developed, which can be gotten by combining the passive muffler 1 and active muffler shown in Fig. 1 together. Figure 6 shows an active-passive hybrid muffler and its performances. The active-passive hybrid muffler has a total length of 500mm, an inner diameter of 100mm and an outer diameter of 270mm. Its performance is related to its mounting position, flow conditions and configurations of pipe. A typical performance curve of active-passive hybrid mufflers is shown in Fig. 6(b) where the noise source is centrifugal fan and the flow velocity is 15m/s. It can be seen that the passive part can effectively attenuate the noise in a broadband frequency range above 200 Hz. The active part can obtain extra more than 6dB noise reduction over 50 Hz-1000 Hz.



(a) Active-passive muffler



(b) Performance

Figure 6. Active-passive muffler and its performance

4. Conclusions

In this work, practical system considerations of active mufflers are investigated further by experiments and a kind of active-passive hybrid muffler is developed. Effects of analogue low-pass filters in the controller, locations of sensors in mufflers and structures of pipe end on ANC performances are studied. The results show that the low-pass filter delay has little affection on the causality of the ANC system. When the muffler is attached at the end of the duct, an error microphone which is placed inside the duct and close to the loudspeaker can be used to control the noise radiated from the outlet of the duct. When the muffler is attached at the middle of the duct, the standing waves in the duct will decrease the ANC performance. Passive and active-passive performances of an active-passive hybrid muffler with optimized parameters are analyzed. It shows that the active part can obtain extra more than 6dB noise reduction over 50Hz-1000 Hz for the case with the flow velocity of 15m/s.

ACKNOWLEDGEMENT

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