Available online at www.eccomasproceedia.org
Eccomas Proceedia COMPDYN (2023) 4997-5002

ECCOMAS
Proceedia

COMPDYN 2023
9th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis (eds.)
Athens, Greece, 12-14 June 2023

ACTIVE NOISE CONTROL OF AIR CONDITIONING SYSTEM NOISE

Orhun Okcu[1], Kanghyun An[2], and Sang-kwon Lee[3]

[1]Inha University
100 Inha-ro, Michuhol-gu, Incheon 22212 Korea
e-mail:orhun.okcu,@inha.edu

[2] Inha University
100 Inha-ro, Michuhol-gu, Incheon 22212 Korea
ankh4059@naver.com

[3] Inha University
100 Inha-ro, Michuhol-gu, Incheon 22212 Korea
sangkwon@inha.ac.kr

Abstract

A HVAC (Heat Ventilation Air Condition) system of passenger seat in autonomous bus is used for heating and cooling of the seat. The compressor of the HVAC system generates the operating noise, and the noise makes passengers annoyance. Frequency spectrum of the compressor noise composes of operating frequency and its harmonics components. Frequency band of operating frequency is low, and that of harmonic frequencies is high. Active noise control (ANC) has been used for reduction of low frequency noise while a passive method using absorption material has been used for attenuation of high frequency harmonic noise. However, some part of harmonic components at low frequency band among harmonic components is not able to reduce by using absorption materials. In this paper, a new ANC method is proposed for the reduction of noise level of low frequency harmonic components based on harmonic flited x-LMS (HFX-LMS) algorithm. The novel method is successfully applied to the noise control of compressor of HVAC system of passenger seat in autonomous bus.

Keywords: FXLMS algorithm, Active Noise Control.

Peer-review under responsibility of the organizing committee of COMPDYN 2023.
doi: 10.7712/120123.10777.20063

1 INTRODUCTION

FXLMS algorithm, today, is widely used in ANC systems. Since the air conditioning system generates low-frequency noise dominantly, the ANC technique can be applied to this system successfully. Therefore, much work has been done recently to suppress this type of noise that is generated by refrigerators because our system mostly resembles the air conditioning system of the refrigerator. However, there is not enough room for a large loudspeaker which can produce low-frequency noise. In this case, to increase the ANC technique's performance, the filter coefficient's low-frequency component can be filtered out [1]. Moreover, the POCS technique has been implemented to increase the performance of the ANC system [2]. In addition, the hybrid techniques, a combination of passive and active techniques, can be used to obtain a reduction in the overall frequency range by designing the air conditioning room in a way that the natural frequency of the air conditioning room is attenuated by the ANC system [3]. Generally, the compressor is dominant in the air conditioning noise. If the natural frequency of the compressor shell is relatively high, the rubber vibration absorber provides sufficient noise reduction for the compressor noise [4].

2 NOISE MEASUREMENTS

Most of the work that has been done before about air conditioning noise has focused on reducing the most dominant noise source, the compressor. In this study, the noise generated from the whole component of the air conditioning noise has been targeted. The sound pressure level measurement has been carried out to identify the frequency content of the noise and the directional properties of the noise. Five microphones have been replaced on the front, back, right, left, and top of the air conditioning system within a 1-meter distance. The experiment setup is shown in Figure 1.

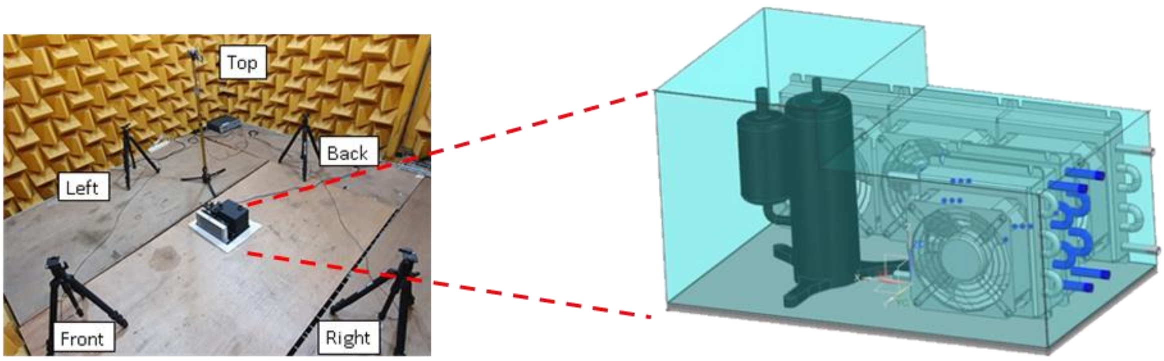


Figure 1: Sound pressure level measurement setup.

The compressor as shown in Figure 1 starts to operate a while after the air conditioning system operates. Therefore, the order of the compressor noise can be determined. The result of the measurement of vibration of the compressor shell is also supported that these frequencies are generated from the compressor. Consequently, the A-weighted sound pressure level (SPL) in the overall frequency range (0-5000 Hz) is presented in Table 1.

Microphones	**Front**	**Back**	**Right**	**Left**	**Top**
Average SPL	46.66 dB	48.46 dB	42.65 dB	46.56 dB	43.25 dB

Table 1: A-weighted sound pressure level of all microphones.

The SPL of the front microphone is the greatest among all microphones because the front microphone picks up both fan and compressor noise.

3 ACTIVE NOISE CONNTROL

The target of the LMS algorithm is to compute optimum filter coefficients that minimize the mean square error. Thus, the iterative steepest descent method is used to determine these filter coefficients. Each iteration is carried out in the direction of the gradient of the error surface [5].

$$W_{n+1} = W_n + \mu(-\nabla_n) \tag{1}$$

The error signal can be expressed as

$$e(n) = d(n) - x(n)W_n \tag{2}$$

Consequently, the gradient of squared error becomes

$$\nabla e^2(n) = -2e(n)x(n) \tag{3}$$

If Equation 4 is substituted in Equation 2, the final LMS algorithm becomes as follows

$$W_{n+1} = W_n + \mu e(n)x(n) \tag{4}$$

where μ is a convergence factor (step size) that controls stability. To avoid divergence which occurs from insufficient spectral excitation, the leaking mechanism is used during the weight update calculation. The leaky LMS algorithm can be written as

$$W(n+1) = \nu W(n) + \mu x(n)e(n) \tag{5}$$

where ν is the leakage factor with $0 < \nu \leq 1$.

There is a trade-off between robustness and the loss of performance while adjusting the leakage factor [5,6].

There are many electronic components such as microphones, filters, and amplifiers between the error microphone and the loudspeaker. This signal path is called the secondary path. Since these components degrade the performance of the ANC system, compensation of the secondary effect is proposed [3]. The system performance can be increased by filtering the reference signal with an identical secondary path filter. Consequently, the widely used FXLMS algorithm is invented. The error signal can be expressed as follows.

$$\begin{aligned} e(n) &= d(n) - \hat{y}(n) \\ &= d(n) - s(n) * y(n) \\ &= d(n) - s(n) * y(n)[\mathrm{w}^{\mathrm{T}}(n)x(n)] \end{aligned} \tag{6}$$

where $s(n)$ is the impulse response of secondary path, $*$ denotes linear convolution. The gradient of squared error can be rewritten as

$$\nabla \mathrm{e}(\mathrm{n}) = -2\hat{\mathrm{x}}(\mathrm{n})\mathrm{e}(\mathrm{n}). \tag{7}$$

Finally, the optimum filter weights are computed by the FXLMS algorithm as follows.

$$\mathrm{W}(\mathrm{n}+1) = \mathrm{W}(\mathrm{n}) + \mu\hat{\mathrm{x}}(\mathrm{n})\mathrm{e}(\mathrm{n}) \tag{8}$$

Since $\mathrm{S(z)}$ is unknown, it can be estimated by an additional filter that is obtained by the separate LMS algorithm. The block diagram of the FXLMS algorithm is shown in Figure 2.

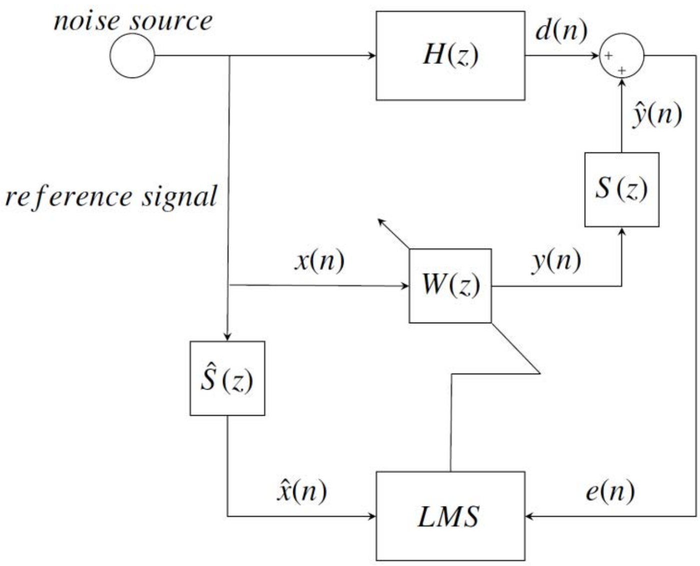
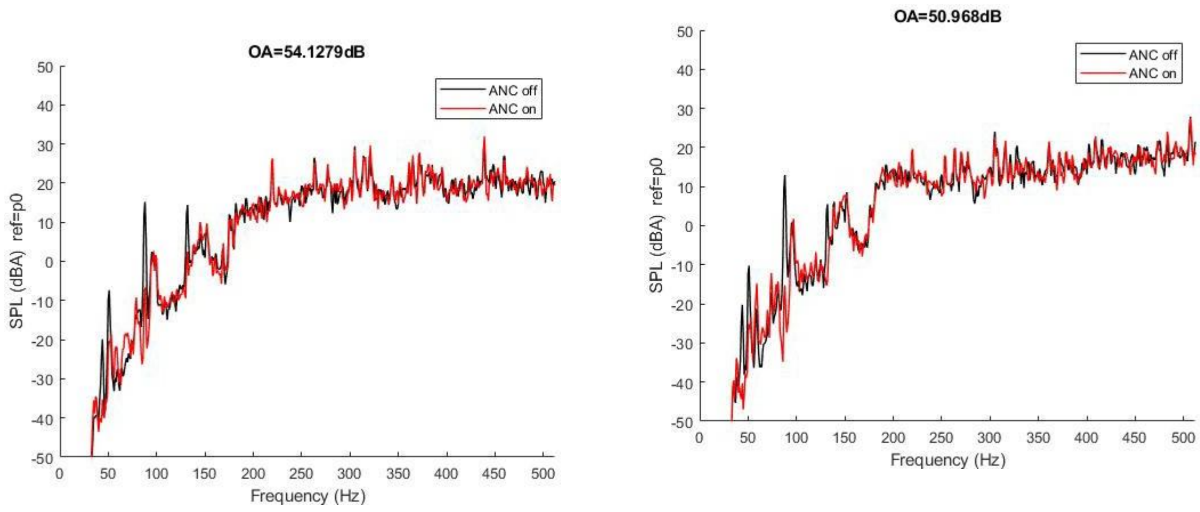


Figure 2: Block diagram of ANC system using the FXLMS algorithm.

4 APPLICATION OF ACTIVE NOISE CONTROLING

The compressor noise is the dominant noise source in the low-frequency region. Therefore, low-frequency drivers and data captured from the accelerometer that is stuck on the compressor shell have used this system. In addition, since the drivers are not directional, a far-field application is suitable for this application. The 44, 51, and 88 Hz which are the order of the compressor noise were controlled by the reference signal from the accelerometer stuck on the compressor shell. Noise at 132 Hz was reduced by using a sine wave generator as a reference signal. Noise reduction ranging from 12 dB to 27 dB has been accomplished for these frequencies at both error microphones. The frequency responses of both error microphones are shown in Figure 6.



(a) Frequency response of front microphone (b) Frequency response of right microphone

Figure 6: Frequency response of error microphones

5 FINAL COMMENTS AND CONCLUSIONS

In this study, the noise characteristic of the air conditioning system has been investigated via sound pressure level and intensity measurements. The FXLMS algorithm has been implemented in the ANC system to attenuate the noise. In the ANC application, the low-frequency noises that are the order of the compressor noise have been controlled by low-frequency drivers. The orders of the compressor noise have been decreased by 12 to 27 dB.

ACKNOWLEDGEMENTS

This work was supported by the grant funded by the Korea evaluation institute of industrial technology (KEIT)(No. 20018706). This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2022R1F1A1062889).

REFERENCES

1. JM Ku, WB Jeong, and C Hong. Active control of compressor noise in the machinery room of refrigerators. Noise Control Engineering Journal, 67(5):350–362, 2019.

2. Jeong-Mo Ku, Weui-Bong Jeong, and Chinsuk Hong. Controller design for active noise controlof compressor by using the time window pocs technique. Journal of Mechanical Science and Technology, 34(7):2693–2700, 2020.

3. DG Smith, MF Arnold, EW Ziegler, Kh Eghtesadi, and M Brown. A systems approach to
4. appliance compressor quieting using active noise control techniques. 1992.

5. Wongul Hwang, Ilkwon Oh, Byounggu Kim, Sungwoo Park, and Kio Ryu. A study on noise
6. radiation from compressor shell. 2006.

7. Sen M Kuo and Dennis R Morgan. Active noise control systems, volume 4. Wiley, New York, 1996.

8. Sang-Kwon Lee, Seungmin Lee, Jiseon Back and Taejin Shin, A New Method for Active Cancellation of Engine Order Noise in a Passenger Car, Appl. Sci. 2018, 8(8), 1394; https://doi.org/10.3390/app8081394