ICIC Express Letters
Part B: Applications
Volume **7**, Number **9**, September **2016**

ICIC International ©2016 ISSN 2185-2766
pp. 1911–1916

STUDY OF NOISE-REDUCTION TECHNIQUE USING AIR PRESSURE CHANGES GENERATED BY A LINEAR MOTOR

Ayato Yamamoto, Shunsuke Ishimitsu, Yoshihiro Aramaki
Daisuke Tanaka and Naoki Shibatani

Graduate School of Information Science
Hiroshima City University
3-4-1 Ozuka-Higashi, Asa-Minami-Ku, Hiroshima 731-3194, Japan
ishimitu@hiroshima-cu.ac.jp

Received February 2016; accepted May 2016

Abstract. *In internal combustion engine development, there needs to be a balance in the relationship between the improvement in the engine performance and the reduction in the engine noise. While it is very difficult to achieve both objectives, active noise control (ANC) presents an effective method to address this issue. With recent advances in digital-signal processing technology, ANC has been used in a number of products. In conventional ANC control methods, a loudspeaker is often used as an actuator; however, the speaker's conversion efficiency is usually too low to control loud noises. In this study, we use a linear motor as the actuator, and we examine the possibility of reducing the noise level via the air-pressure change in the cabin. We investigate the performance of the speaker and the linear motor when controlling a loud noise, and we confirm the effectiveness of the linear motor. The results show that there is efficient control of the air pressure change.*

Keywords: ANC, Engine sound, LMS algorithm, Sound of acceleration, Reference signal

1. **Introduction.** It is difficult to achieve simultaneous improvements in engine performance and engine-noise reduction because of the trade-off in their relationship. One of the effective methods employed to solve this problem is to use active noise control (ANC), which reduces noise by using interference control, and which introduces sound having the same amplitude and opposite phase to the target sound [1]. ANC has a number of advantages. First, it is effective for low-frequency noise, which is difficult to reduce using conventional passive-reduction approaches such as sound insulation, soundproofing, or the use of sound-dampening materials. Second, it can be installed in a smaller space compared to that required by conventional passive-reduction methods. Thus, ANC has been used to reduce the interior noise of vehicles [2,3].

Generally, a loudspeaker is used as an actuator in ANC systems. However, the conversion efficiency of the speaker is too low to control loud noises. In a previous study [4], we applied a linear motor as the actuator, and we examined the possibility of reducing the noise level by performing air pressure change. As a result, under the control of the filtered-x least mean squares (FxLMS) algorithm [1], the low-frequency noise (0-120Hz) was reduced. However, the results at high frequencies (150-500Hz) worsened. Therefore, the harmonic filtered-x least mean squares (HFxLMS) algorithm [5] was introduced and the target frequency band was also changed to a low frequency to prevent the deterioration of ANC.

2. **System Overview.** Figure 1 shows the system configuration that we employed. In this study, the control target was the noise in a cylindrical tube. The full size of the cylindrical tube is 112mm wide by 520mm deep.

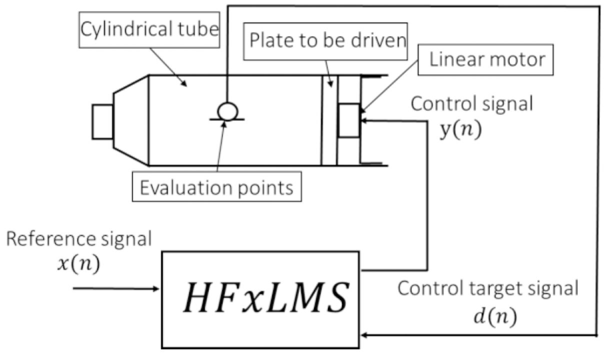

Figure 1. Structure of the system

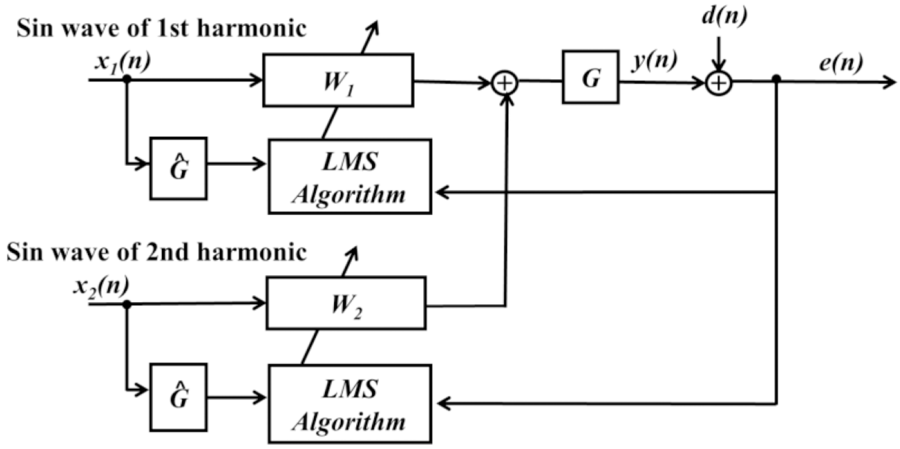

Figure 2. Block diagram of the HFxLMS algorithm

Figure 2 shows a block diagram of the HFxLMS algorithm, which is used to control the fundamental and second frequency components. In Figure 2, x is the reference signal, W is the adaptive filter, G is the transfer function (between the linear motor and microphone), $\hat{G}$ is the modeling transfer function, d is the desired signal, μ is the convergence coefficient, and each subscript is an order component. The reference signal, x, is generated as a tonal reference signal that corresponds to engine order components. This tonal reference signal, which consists of the fundamental component as well as those from each order, can be determined from the period of the engine pulse signal, and it is generated on the digital signal processor (DSP). The control signal, y, is then expressed by Equation (1). The order is shown by M.

$$y(n) = W_1(n)x_1(n-i) + \cdots + W_M(n)x_M(n-i) \tag{1}$$

The error signal is e, and is expressed by Equation (2).

$$e(n) = d(n) + \sum_{i=0}^{N-1} G(i)y(n-i) \tag{2}$$

The adaptive filter W (with filter length N_w), which reduces the error signal, is then expressed by Equation (3).

$$W_M(n+1) = W_M(n) - \mu e(n) \sum_{i=0}^{N-1} \hat{G}(i)x(n-i) \tag{3}$$

Figure 3 shows the device, which has a linear motor that is able to control a plastic wall. We attached cloth to the wall to reduce the friction. We mounted a linear motor

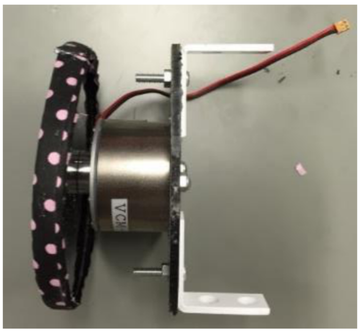

Figure 3. Device that we used in the examination

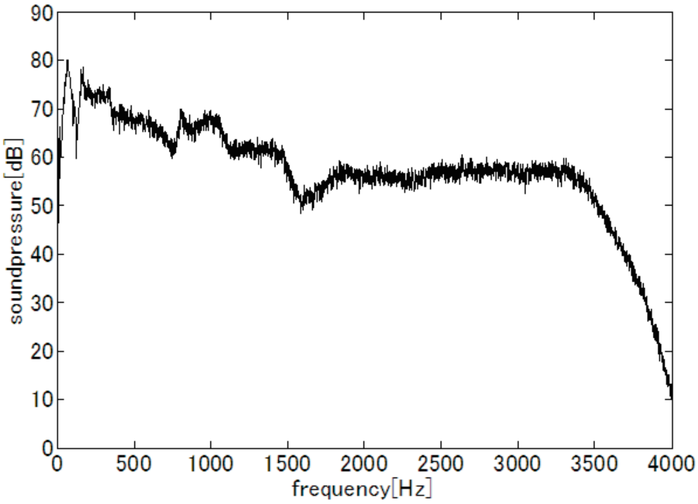

Figure 4. Frequency properties of the device

using L-shaped metal fittings and a bolt located in the cylindrical tube. The linear motor was a VCM-6143 (Kurashiki-Kako Company), which controlled the movement of the plate using an electromagnetic force. The length of the drive portion was 1cm. The control signal y is output to vibrate the panel and control the air-pressure change. The full size of the device is 110mm wide by 70mm deep. Figure 4 shows the frequency properties of this device.

3. **Experiment.**

3.1. **Experimental method.**

In this study, we applied the HFxLMS algorithm to reduce the noise in the cylindrical tube, and we compared the results of the noise level at the evaluation point with the speaker and the linear motor.

The engine sound was recorded via a microphone (MI-1431, Ono Sokki Co., Ltd., Japan) at a sampling frequency of 8120Hz. The driving conditions were steady-state operation at 3000rpm.

In the experiment, we used the HFxLMS algorithm with an ignition trigger pulse as a reference signal and the engine sound of the four-cylinder four-cycle engine as the desired signal. In our experiment, the fundamental frequency of the engine sound produced at 3000rpm was 25Hz. The control targets were 1st-4th order components, and the tap length of the adaptive filter was 1024. We used the reference signal for each of the 1st-4th order components. The desired signal was the engine sound.

3.2. **Experiment results.**

Figures 5-8 show experimental results obtained for the steady-state operation. The solid line shows the state before control, while the broken line shows the state after control. Figures 5 and 6 show each result with the speaker and the linear motor, and the control targets were 1st-4th order components (25, 50, 75, and 100Hz). The solid red line is the result with no control, while the dashed blue line is controlled. Figures 7 and 8 show the enlarged view at 0-150Hz. In Figure 7, where the noise was controlled using the speaker, the noise level of the 1st-4th order components was reduced by 4.9dB, 2.5dB, 1.4dB, and 0.3dB respectively, and the overall value was reduced by 0.4dB. In Figure 8, where the noise was controlled using the linear motor, the noise level of the 1st, 2nd, and 4th order components was reduced by 13.3dB, 5.0dB, and 13.0dB respectively. The noise level of the 3rd order component was decreased by 5.4dB, but the overall value was reduced by 2.1dB. In Figures 5 and 6, for both the speaker and the linear motor, the high-frequency noise did not increase.

3.3. **Discussion.** We used the HFxLMS algorithm, and we compared active control using the speaker and the linear motor. From the reduction in the overall value, we found that control using the linear motor was more effective for loud noise; however, the 3rd order component worsened. This was caused by errors in the transmission function, which resulted from the characteristics of the linear motor.

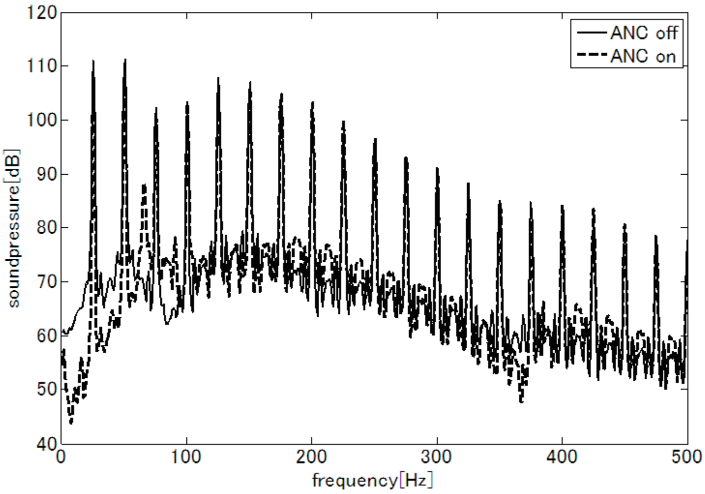

FIGURE 5. Experimental result of the control of the speaker (500Hz)

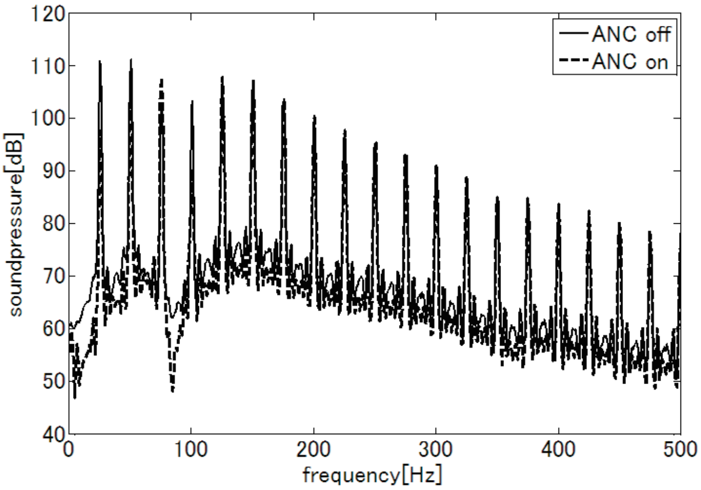

FIGURE 6. Experimental result of the control of the linear motor (500Hz)

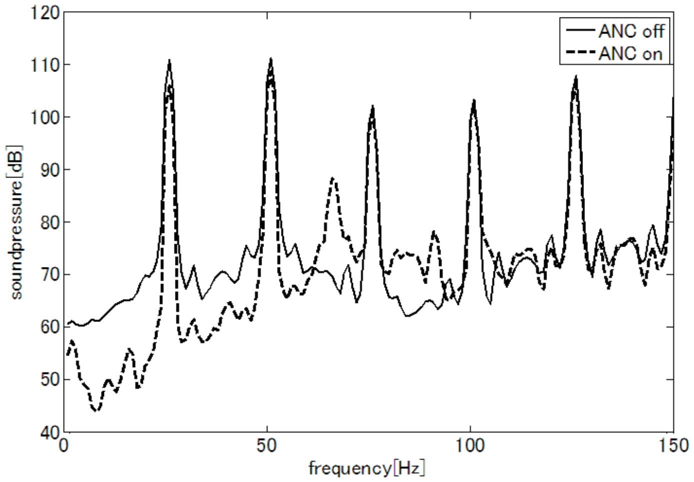

Figure 7. Experimental result of the control of the speaker (150Hz)

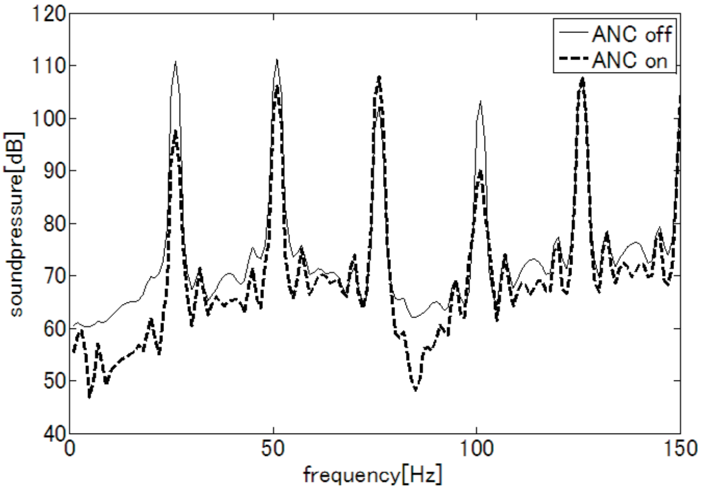

Figure 8. Experimental result of the control of the linear motor (150Hz)

4. **Conclusion.** In this study, we examined the possibility of reducing noise levels by varying the air pressure using a linear motor. Using the HFxLMS algorithm, we confirmed a reduction in the low-frequency noise using the HFxLMS algorithm; however, the 3rd order component worsened. In future work, we will investigate the effect of increasing the number of linear motors, and we will change the location of the linear motor and the vibration board to improve stability.

REFERENCES

[1] M. Nishimura, T. Usagawa and S. Ise, *Active Noise Control*, Corona Publishing Co., Ltd., Japan, 2006.

[2] M. Nishi, D. Ochi, Y. Nakaji, H. Nagai, M. Mizuochi and H. Mineura, Development of ANC technology for reconciling acceleration sound with fuel economy and quietness, *Society of Automotive Engineers of Japan*, no.306, pp.7-10, 2010.

[3] T. Inoue, Active noise control technology in automobiles, *Society of Instrument and Control Engineers*, vol.51, no.12, pp.1143-1149, 2012.

[4] A. Yamamoto, S. Ishimitsu, T. Sagawa, Y. Aramaki, K. Namekawa, T. Takagi and K. Yoshida, Noise reduction method using air pressure variation using a linear motor, *Journal of the 17th IEEE Hiroshima Branch Student Symposium*, 2015.

[5] T. Ueganiwa, S. Ishimitsu, K. Namekawa, T. Takagi, T. Chino, K. Yoshida and K. Suzuki, Improvement of convergence property using harmonic components, *Transactions of the JSME in Japan*, vol.51, no.603, 2013.