TWO TYPES OF ACTIVE NOISE CONTROL SYSTEM USING MFB LOUDSPEAKER

Yoshitaka Nishimura, Yasuyuki Shimada, Tsuyoshi Usagawa and Masanao Ebata

Department of Electrical Engineering and Computer Science
Kumamoto University, 2-39-1 Kurokami, Kumamoto 860, JAPAN
E-mail : taka@eecs.kumamoto-u.ac.jp (Y. Nishimura)

ABSTRACT The impedance of an electro-acoustic transducer can be controlled by motional feedback, and the noise in a duct can be reduced actively by adjusting the impedance using an additional sound source. In this paper, two approaches for active noise control using motional feedback (MFB) loudspeaker are described. First configuration uses an external sensor to pickup of source directly. In this configuration, the adaptation of controller is necessary to compensate the change of transfer function from noise source to control point. The second configuration uses a new adaptive algorithm specialized for periodic noise. Because this configuration does not require any reference input and the error sensor couples very tightly with control loudspeaker, this MFB system itself is independent of the duct condition. No microphone are required in both configurations, so that a more reliable and stable active control system can be realized under severe conditions such as high pressure, high temperature, dust, flow and so on.

1. INTRODUCTION

The importance of the active noise control (ANC) and the active vibration control (AVC) techniques is not necessary to mention here, however the simplicity of system configuration is still very important issue. A simpler ANC or AVC system has advantages in reliability and cost requirement.

The authors have studied an ANC system using only a single motional feedback (MFB) loudspeaker which works not only as an actuator but also as an error sensor[1][2]. According to the theoretical analysis, it was made clear that the effective frequency range of this system is mainly lower than the resonance frequency of MFB loudspeaker, and it is not wide compared with conventional ANC systems using microphones and loudspeaker. This limitation comes from the causality of controller like so called tightly coupled ANC system[2]. However, this limitation is not met for a periodic noise, such as an exhaust noise of engine, and there are many application fields of ANC for a periodic noise.

In this paper, two configurations of ANC system using MFB loudspeaker are proposed. The first configuration uses conventional least means square (LMS) adaptive algorithm with external reference signal so that it is effective for wide band noise. The MFB loudspeaker works as an actuator and an error sensor simultaneously. The second one uses a new adaptive algorithm specialized for periodic noise. This adaptive algorithm works as harmonics synthesizer and it requires the information about fundamental frequency of harmonics.

2. MOTIONAL FEEDBACK SYSTEM

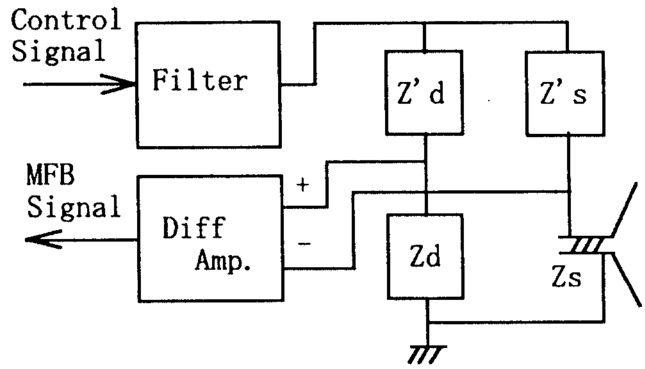


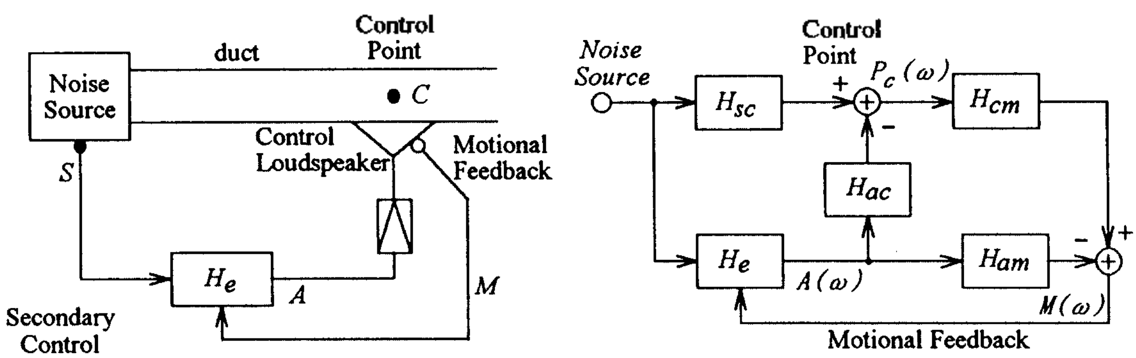
Fig. 1 Pickup Method using Bridge

Figure 1 shows the pickup method of motional component using bridge circuit. The requirement for arms of bridge circuit is

$$\frac{Z_d'}{Z_d} = \frac{Z_s'}{Z_s}, \quad |Z_d| \gg |Z_s|. \quad (1)$$

As shown in this figure, the motional feedback is used as an error input so that there are several advantages compared with conventional microphone based system. At first, it is simple ; only a loudspeaker and a controller are required except a sensor to pick up rotational speed of engine. And secondly, the amount of delay due to error path is not affected by temperature and others, because the duct itself is not included in the error path. Thirdly, the possibility of unstableness or oscillation becomes small because the filter never synthesize signal other than specified harmonics.

3. CONFIGURATION 1: MFB SYSTEM WITH EXTERNAL PICKUP



(a) Configuration (b) Block diagram

Fig.2 MFB Active Control System with an External Pickup

The first configuration uses the MFB loudspeaker as a error sensor for the adaptation of controller and noise signal is obtained by a external pickup as shown Fig.2. In this configuration we need to implement the adaptive controller to track a change of condition, such as a temperature, speed of airflow and so on, because the required transfer function depends on the condition of duct. First of all, a characteristic of $H_{am}(\omega)$ and $H_{acm}(\omega)$ in Fig.2(b) are required to design the controller.

The error $E(\omega)$ for adaptive control can be obtained as follows,

$$E(\omega) = M(\omega) - A(\omega)\hat{H}_{am}(\omega) \approx P_c(\omega), \quad (2)$$

where $\hat{H}_{am}(\omega)$ is an estimate of $H_{am}(\omega)$.

Because SNR of error signal limits the maximum performance of controller, the performance of adaptation is regarded by noncoherent noise. Furthermore when the control becomes effective, the input of loudspeaker is increased so that the SNR condition becomes more severe. The SNR of sensor depends on the balance of bridge circuit for MFB pickup. Although the difficulty of SNR, this configuration can control wider frequency range than the one of former MFB system[1]. The causality of controller can be satisfied when the time delay between pickup and loudspeaker is longer than that of controller. However, the size of controller is one of important issue to realize the active control system for exhaust noise.

4. CONFIGURATION 2 : MFB SYSTEM FOR PERIODIC NOISE

4.1 Delayed-X Harmonics Wave Synthesizer Algorithm

Large part of noise can be classified into periodic noise. An exhaust noise of engine is one of the most popular examples and it is composed of several harmonic components with the fundamental frequency related to the rotational time. To utilize ANC technique to such a periodic noise, we have several choices for configurations of controller. A controller based on the filtered-x least mean square algorithm (FX-LMS) is widely used. This configuration requires a reference input which has all components to be controlled. Although the FX-LMS is very attractive and it can be used for variety of applications, a computational load is rather large when the requirement of cost is very severe and the convergence speed is not always sufficient.

The alternatives are also proposed to reduce the computational load and the convergence time. The first alternative is one based on the synchronized filtered-x (SFX) algorithm[3]. The SFX algorithm assumes that noise is periodic and synchronized to a reference input. The output of algorithm is composed only by summation of filter coefficients and it does not required any multiplies. It seems to be attractive to reduce the computational load, but to achieve sufficient performance the sampling frequency should be much higher than the nyquist frequency. The second alternative is a single-frequency adaptive notch (SAN) filter [4]. This configuration uses a sinusoidal signal as a reference to control single frequency component of noise.

Like SAN filter algorithm, a certain sinusoidal signal can control specified component of noise. When noise is periodic and it has obvious peak at a specific harmonic component, such as an second harmonic of rotational speed for 4 cylinder engine. To realized such a sinusoidal signal, only amplitude and phase need to be adaptive because frequency can be obtained by external sensor.

Let us concern to cancel periodic noise $d(n)$ described as follows,

$$d(n) = \sum_{k=1}^{L} a_k^* \exp\left\{ j\left(k\,\omega^* nT + \phi_k^*\right)\right\}, \tag{3}$$

where L is a number of harmonic components and T is a sampling interval. And the controller synthesize $M(M \le L)$ harmonic waves. A synthesized signal $y(n)$ is given as,

$$y(n)=\sum_{k=1}^{M} a_k \exp\{j(k\,\omega nT+\phi_k)\},\qquad (4)$$

where a_k^* and ϕ_k^* are an amplitude and a phase for k-th harmonic, respectively.
And ω^* is a fundamental angular frequency of noise. And a_k, ϕ_k, ω are ones for synthesized signal. The frequency ω^* can be treated as a constant and it can be measured directly or indirectly by an external sensor, so that the frequency of synthesized signal ω is set as ω^*. Adaptive algorithm can be designed to minimize a instantaneous error function J shown as,

$$J=e^2(y(n)+d(n))^2 \qquad (5)$$

by means of controlling coefficients vector $W(n)=[\ldots a_k(n)\ldots,\ldots\ \phi_k(n)\ldots]^T$ The gradient vector, $\nabla(n)$, can be given as follows,

$$\nabla(n)=\frac{\partial J}{\partial W(n)}=\begin{bmatrix}\vdots\\ \frac{\partial}{\partial a_k}\\ \vdots\\ \frac{\partial J}{\partial \phi_k}\\ \vdots\end{bmatrix}=\begin{bmatrix}\vdots\\ 2e(n)\exp\{j(k\,\omega nT+\phi_k(n))\}\\ \vdots\\ j2e(n)a_k(n)\exp\{j(k\,\omega nT+\phi_k(n))\}\\ \vdots\end{bmatrix}. \qquad (6)$$

This means that the update of amplitude and phase parameter can be done as follows,

$$W(n+1)=W(n)-\begin{bmatrix}\vdots\\ 2\mu_a e(n)\exp\{j(k\,\omega nT+\phi_k(n))\}\\ \vdots\\ j2\mu_p e(n)a_1(n)\exp\{j(k\,\omega nT+\phi_k(n))\}\\ \vdots\end{bmatrix} \qquad (7)$$

where μ_a and μ_p are the step size parameters for amplitude and phase, respectively. When this algorithm is used for ANC and AVC application, delay for each harmonic due to error path need to be taken into account. When delay for k-th harmonics is m_k, n for corresponding element to k-th harmonics in Eq.6 should be replaced by $n-m_k$. Actual algorithm used on controller is written by only real value. We call the algorithm as a Delayed - X Harmonics wave Synthesizer algorithm (DXHS) here after.

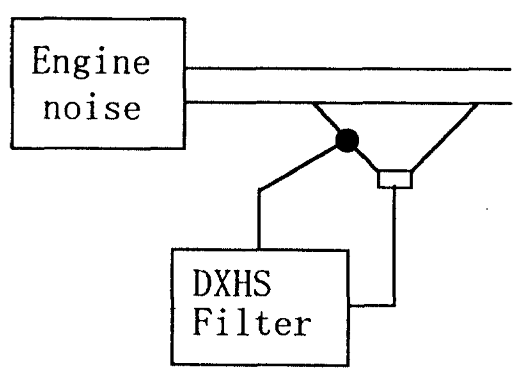


Fig. 3 Configuration of Active Control System using DXHS Algorithm with MFB Loudspeaker

4.2 System Configuration

Figure 3 is the diagram of system where the delayed-x harmonics wave synthesizer algorithm is implemented as the ANC filter. In this configuration, the error sensor couples very tightly with control loudspeaker, so that MFB system itself is independent of the duct condition. Delay is not depend on the duct condition so that it can be measured separator.

5. EXPERIMENTAL RESULTS

Two model experiments are carried out using a recorded exhaust noise of diesel engine which is equipped on a $17kWh$ electric power generator. Rotational speed of diesel engine is controlled at $1800rpm$ by means of mechanical governor.

5.1 Configuration 1

Figure 4 is the results of model experiment using the first configuration. In this figure, dotted lines shows spectrum of original engine noise and solid lines shows controlled one. The attenuation is about $7dB$ at $120Hz$ because the SNR of error signal is not high.

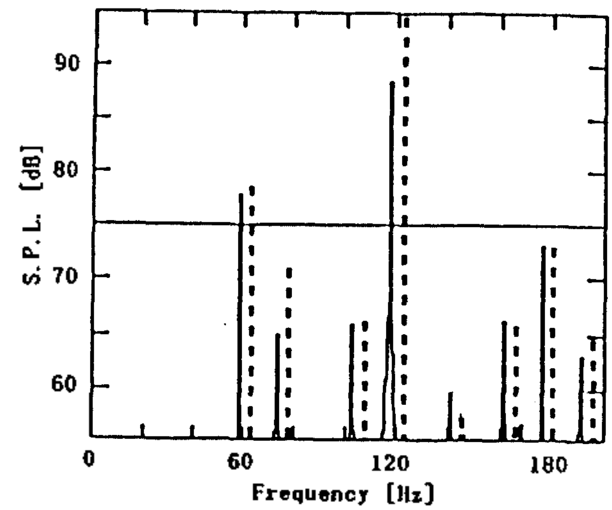
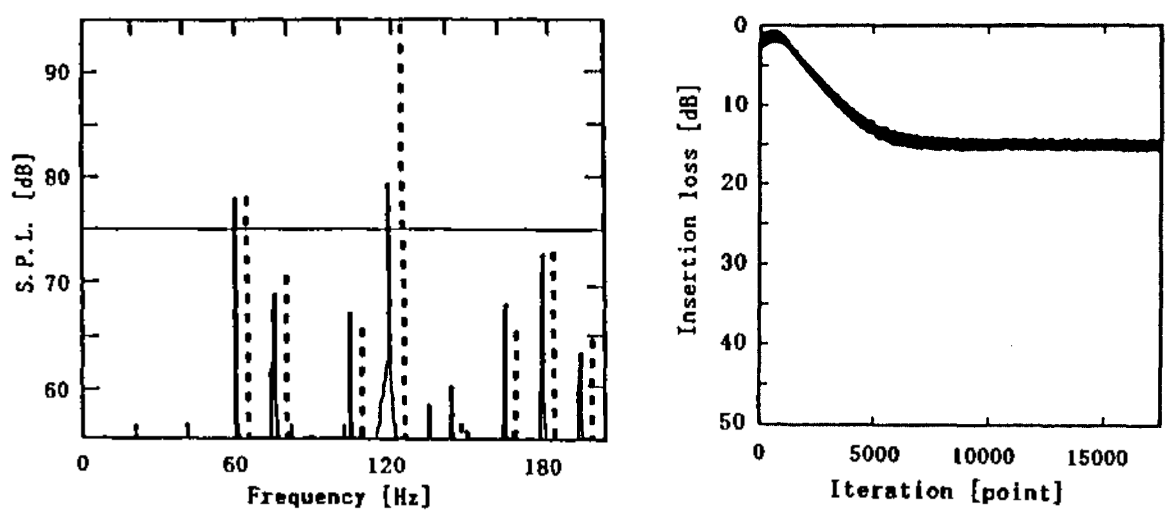


Fig. 4 Results of Model experiment using the first configuration : spectra of original(dotted) and controlled(solid) noise

5.2 Configuration 2

The DXHS filter works at $3.6kHz$ for a single frequency : $120Hz$. Figure 5 (a) shows the results of experiment as the spectra original(dotted)and controlled(solid) noise. Also the time



(a) Spectra of Noise (b) Convergence Characteristics

Fig. 5 Results of Model experiment : (a) spectra of original(dotted) and controlled(solid) noise, and (b) Convergence Characteristics of Overall Noise Level history of overall noise level measured at outlet of duct is shown in Fig.5 (b). Note that the absolute time to achieve 10 dB attenuation is less than $1.2S$.

6. CONCLUSION

This paper mentioned two configurations of ANC using MFB loudspeaker and proposed a new adaptive algorithm for periodic noise . The first configuration uses an MFB loudspeaker with an external reference input. The second configuration using a new adaptive algorithm specialized for periodic noise. Both configurations did not require any microphones, so that the improvement of durability of these control systems is easier compared with one of conventional microphone loudspeaker type system. The model experiments are carried out using an exhaust noise of diesel engine. The maximum attenuation obtained by the first configuration is $7dB$ and one by second configuration is $15dB$.

REFERENCES

1. J.Okda, T.Nishimura, Y.Nishimura, T.Usagawa and M.Ebata, "Active Noise Control System using Motional Feedback Loudspeaker," J.Acoust.Soc.Jpn.(E), 12(6), pp.291-297 (1991)

2. T.Usagawa, H.Furukawa, Y.Nishimura and M.Ebata, "Active Control of Engine Exhaust Noise using Motional Feedback Loudspeaker," Proc. 2nd conf. of Recent Advances on Active Control of Noise and Vibration, Virginia Polytech, pp.837-847 (1993)

3. H.Hamada, K.Ito, S.Uto and T.Miura, "Synchronized Filtered-x Algorithm and its application to Active Control of Sound and Vibration," Proc. Acoust.Soc.Jpn., No.3-5.13 (1992,3) (in Japanese)

4. K.Ito, I.Miyasaka, S.Uto and H.Hamada, "Implementation of Active Control System using Single-Frequency Adaptive Notch Filter," Proc. Acoust.Soc.Jpn., NO.1-9-12 (1994.3) (in Japanese)