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Application of active noise control to car intake system

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Abstract

Engine intake noise of automobile is another important noise that irritates drivers and passengers. The intake noise is narrow-banded low frequency noise. And it varies with engine rpm and throttle condition. Active Noise Control (ANC) technique is superior to passive noise control for this low-frequency noise. ANC is applied to four-cylinder automobile engine intake system. Normalized FXLMS (Filtered-X Least Mean Square) algorithm is used to suppress the intake noise. Two loudspeakers are used for actuator and microphone is used for error signal and reference signal. For stationary case, descending and ascending rpm condition and various throttle opening conditions are applied. ANC successfully suppresses engine intake noise emission. For stationary rpm case, the loudest second order component is attenuated by 20dB. For RPM transition rate of 200rpm/sec case, second order component is attenuated by 10dB.

1. Introduction

Automotive engine noise has low frequency characteristics. So, It is good candidate for Active noise control. Exhaust noise and Intake noise attenuation is good research topic for ANC. Active noise control systems for air induction systems has not received as much attention as in exhaust systems [1][2]. Engine is frequently accelerated and decelerated with throttle opening and closing when cars are on the road. Consequently, engine noise varies very quickly and frequently in frequency and magnitude. Ability to track engine noise variance is needed for Active control system for intake noise. Intake Noise acoustic power is very large in four-cylinder engine. Powerful low-frequency range loudspeaker is required. But intake duct diameter is not so large compared to loudspeaker diameter. So effective loudspeaker installment is need. Two 6-inch speakers are attached to intake duct via converging horn.

2. Control Algorithms

The most widely used algorithm in ANC applications is time-domain Filtered-X LMS algorithm, owing to its simplicity and robustness [3][4]. In order to improve the controller performance with regard to convergence rate, noise attenuation and tracking performance, it may be possible to use faster, more efficient algorithm. However, faster algorithms are complex and therefore demand greater computational capacity in the control system. When computational power is limited, simple algorithm with more iteration is another solution for convergence rate, and tracking performance.

The applied multi-channel control algorithm is Feedforward Normalized Filtered-X LMS algorithm for narrow-band noise. Intake noise signal characteristic varies rapidly corresponds to engine rpm and throttle opening angle. Control algorithm applied to intake noise must satisfy both fast tracking to input signal variance and stability despite of rapid change in reference signal. Normalization of reference signal and Leaky factor is used to satisfy fast tracking and stability. Single channel input-output Normalized algorithm can be described as follows.

$$\begin{aligned} e(n) &= d(n) - y(n) \\ &= d(n) - W^T(n)X(n) \end{aligned} \quad (1)$$

$$w(n+1) = \nu w(n) + \mu(n)x(n)e(n) \quad (2)$$

$$\nu = 1 - \mu\gamma \quad (3)$$

$$\mu(n) = \frac{\alpha}{L\hat{P}_x(n)} \quad (4)$$

$$\hat{P}_x(n) = (1-\beta)\hat{P}_x(n-1) + \beta x^2(n) \quad (5)$$

x : Reference signal

y : Output signal

e : Error signal

d : Desired response

ν : Leaky factor

X : Input signal vector

W : Weight vector

μ : Step size

β : Forgetting factor

Because most energy of Intake noise exists below 500Hz range, and case of throttle wide open, second order component is above 120dB. Overloading at loudspeaker may arise. Leaky factor is used to prevent excessive speaker output.

The stability, convergence time, and fluctuation of the LMS adaptation process are governed by the step size μ and the reference signal power. To optimize the speed of convergence while maintaining the desired steady-state performance, despite of rapid variation of reference input signal.

3. Experimental Setup

The experiments were performed at the anechoic chamber of Hyundai Motors Company. Hyundai motors beta engine with 4cylinder, 1.5-liter volume was tested. The engine was coupled to dynamometer. Engine exhaust was tipped out of the test cell. Two speakers are attached to air duct via converging pipes. Attenuation device such as resonator is removed and loudspeaker is installed at the position where resonator existed. Considering applicability in manufacturing, chief microphones are installed at the position of manifold and air duct. To avoid interference from flow turbulence, small slit was made at the duct wall. Small cavity with absorbing material is attached to cavity and microphone is installed in it. The signal driving the speaker is generated by a TI320C44 DSP based controller manufactured by Innovative integration. The controller output signal passes through a two channel audio amplifier. Sampling rate of A/D and D/A was 4kHz. Other engine noises are not separated well. Results are measured from 5cm from the intake duct.

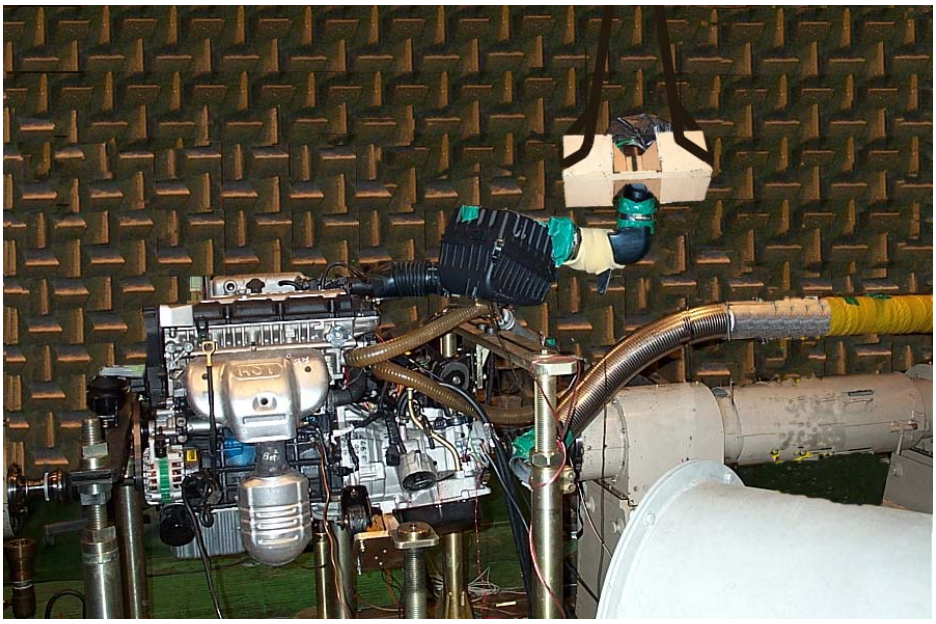

Figure 1: Engine Test cell showing engine, dynamometer, and loudspeaker.

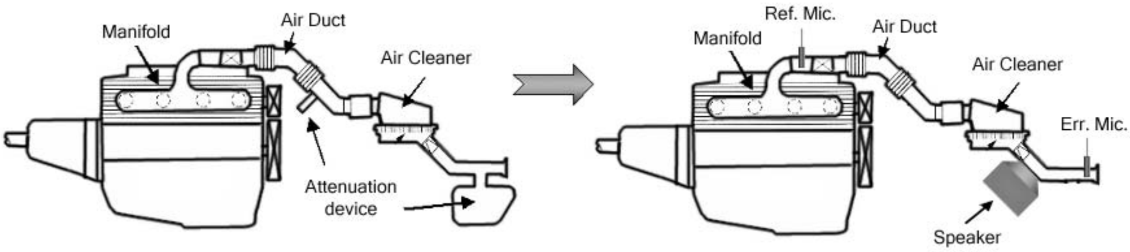

Figure 2: Original intake configuration and Configuration with active noise controller. Attenuation device is removed.

4. Test Results

Stationary cases and sweeping cases were tested. In Stationary test, rpm and throttle opening angle are fixed. Rpm and throttle opening were from 2000rpm to 4000rpm, from 30% to 100%. In sweeping test, engine rpm is increased and decreased with throttle opening and closing between 2000rpm and 4000rpm. Rpm sweeping rate is 100rpm/sec and 200rpm/sec.

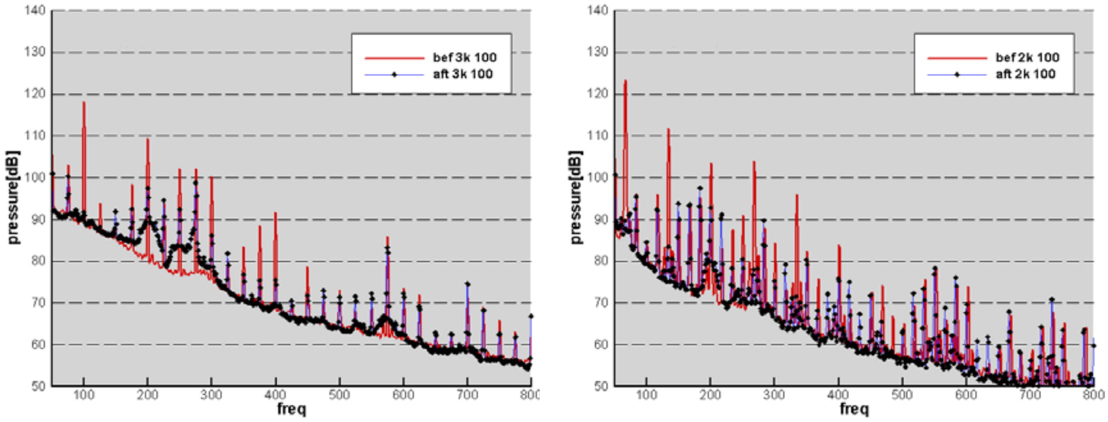

Figure 3: Spectra with and without active control. Rpm is fixed at 3000rpm, 2000rpm each case, 100% throttle opening.

Stationary case of 2000 and 3000rpm, throttle wide opening, dominant 2nd order harmonic (2nd order of RPM, and 1st order of firing) is suppressed about 30dB. And 3rd, 4th order is also attenuated above 10dB. At other RPM, throttle condition, Active Noise Controller successfully attenuate dominant 2nd order component above 20dB.

Sweeping case from 2000rpm to 4000rpm in 10sec is plotted at figure 4 and figure 5. Deceleration case showed similar attenuation level. In figure 4, the spectral lines associated with the controlled orders were reduced consistently when the active noise control was switched on.

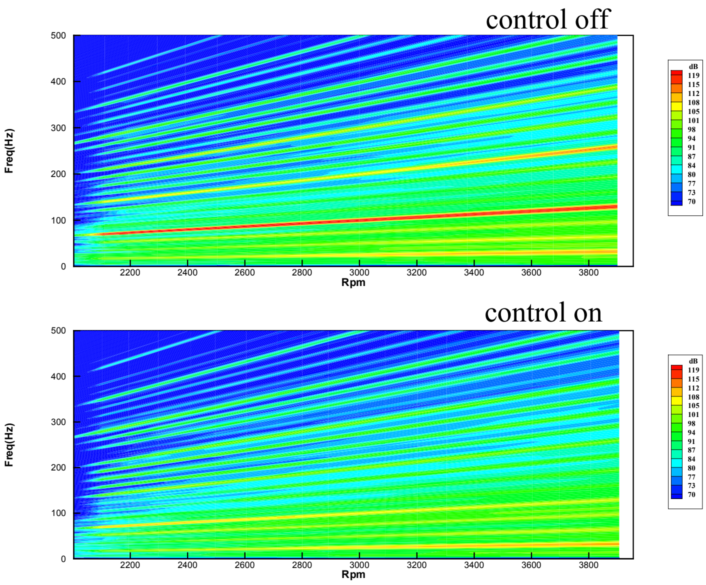

Figure 4: Rpm is increased from 2000rpm to 4000rpm in 10sec. Upper plot is for control off case. Lower is control on case.

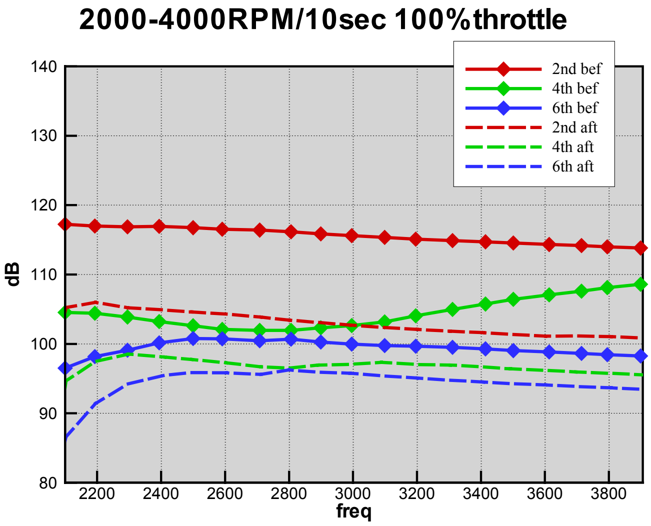

Figure 5: Order component comparison with control to without control for 200rpm/sec sweeping case

5. Conclusion

Normalized Filtered-X LMS is applied to four-cylinder engine intake system with two loudspeakers, a reference microphone and an error microphone. Both stationary case and sweeping case, active noise controller shows robust and good tracking performance. At the rate of 200rpm/sec, dominant first order component is attenuated by 20dB. For practical application, loudspeaker and cases size should be much smaller than resonator.

Acknowledgements

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