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Research on the Effect of Parameter Selection on Engine Noise Control in FXLMS Algorithm

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Abstract. In order to reduce the induction noise of automobile engine, an active control system model of engine induction noise is established with the FXLMS algorithm, the off-line identification method is used to identify the secondary channel, and the engine speed signal is used to construct the sound source reference signal to avoid the interference from secondary sources to the reference signal. The influence of filter length and convergence factor on the convergence speed and stability of the system is studied by simulation, the average power of the noise signal and the error signal is calculated, the noise variation at different engine speeds is analyzed, and the noise reduction effect and system stability are evaluated. The results show that when the filter order L is 20 and the convergence factor is 0.01, the engine induction noise can be effectively reduced, the noise reduction can reach 15dB, and the system stability can be improved at the same time. This paper optimizes the convergence factor and the filter order in the FXLMS algorithm, and can effectively control the induction noise in the car and improve the indoor sound quality of the car. It has important reference significance for practical engineering applications.

Keywords: FXLMS algorithm, active control, induction noise, rotational speed

1 Introduction

While bringing convenience to people, automobiles also bring problems such as environmental noise pollution [1-2]. The noise in the car has a great influence on the ride comfort and customer satisfaction of the car. People are paying more and more attention to lowering the car noise. Conventional noise reduction methods, such as sound insulation, vibration isolation, and muffler, are basically ineffective for low-frequency noise control [3]. The active noise control method is effective because of its low frequency noise reduction and can be targeted [4-5]. In recent years, with the development of electronic technology, active noise control has been widely concerned and discussed by researchers.

The application of noise active control technology in the cabin in 90s has been widely concerned. Lockheed and P.A.Nelson in Nanan University in the United Kingdom have tested the active control of aircraft cabin noise respectively, and achieved good reduction effect. It is proved that the noise active control technology is in aircraft, ships and cars, etc. the wide prospect of cabin application is [6]. The British Lotus motor company applied the active noise control technology to the gas vehicle, and obviously reduced the low frequency harmonic order noise of the engine in the vehicle. The roar in the

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car that corresponds to the harmonic noise of the engine ignition frequency can reduce about 10dB [7]. NISSAN Japan has equipped the active noise control system on the vehicle with Blue Bird, which can reduce the noise inside the vehicle by about 5~6dB [8].

In the past, the study of active noise control in the vehicle has been carried out. The acoustic sensor is used to collect the primary source noise signal as a reference signal. The method can easily produce sound feedback in the process of controlling the control system and affect the stability of the control system. In this paper, a method of constructing the intake noise reference signal with engine speed signal is proposed. The experimental study of active noise control through simulation shows that the system is simple and easy to be realized, and it can significantly reduce the internal noise caused by the engine intake system.

2 Ease of Use Basic Principle of Active Noise Control

The idea of active noise control is based on the principle of wave interference in physics. It uses the characteristics that the secondary sound source and noise signal have the same amplitude and opposite phases, so as to achieve the purpose of eliminating noise. The adaptive algorithm is the core of the control system. Whether it is feed forward or feedback, most active noise control systems use LMS algorithm and its improved algorithm to adjust the controller weight coefficient. Because of the presence of the secondary sound path, the standard LMS algorithm makes the reference signal and the error signal unequal in time, resulting in instability of the active noise control system. In this way, adding the weight estimate of the secondary acoustic transfer function between the reference signal and the error signal can effectively improve the stability of the system, that is, generate a new algorithm--FXLMS algorithm. The FXLMS algorithm uses the acoustic path model to filter the reference signal, uses the filtered reference signal and the output error of the system to update the filter coefficients, and then corrects the controller. There by replacing the acoustic path in actual transmission with the estimated acoustic path [9]. This paper adopts feed-forward FXLMS algorithm to study the filter order, convergence factor and noise control effect. The structure is shown in Fig. 1.

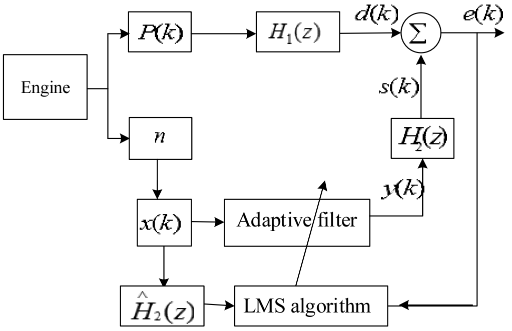


Fig. 1. Active noise control system model of FXLMS algorithm

In Fig. 1, k is the sampling time; n is the engine speed; $P(k)$ is the primary noise source; $d(k)$ h is the output of main channel; $x(k)$ is the reference signal; $y(k)$ is the drive signal of secondary sound source; $s(k)$ is the output signal of secondary sound source at the error signal sensor, $e(k)$ is the error signal; $H_1(z)$, $H_2(z)$ is the transfer function of the primary and secondary channels; $\hat{H}_2(z)$ is the transfer function of the secondary channel is estimated.

As we all know, the acoustic transfer function of the single-frequency periodic signal can be obtained by the actual measurement method in Fig.1, but the engine rotation speed during the running of the car is continuously changed, and the frequency of the single-frequency periodic signal also changes, so it is difficult to obtain the transfer function the in Fig. 1. In this paper, the transversal FIR filter of the LMS algorithm is used as a modeling filter. Off-line modeling is used to estimate the transfer function in Fig. 1 in this case, as shown in Fig. 2.

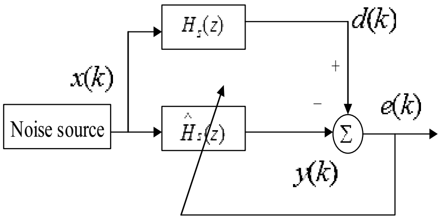


Fig. 2. $H_2(z)$ Schematic diagram of offline identification structure

In Fig. 2, the secondary channel $H_s(z)$ as an untested system or an unknown system, and its output $d(k)$ is expressed as the desired signal identified by the system; white noise x is the excitation signal; $y(k)$ is the output of the secondary channel estimate $\hat{H}_s(z)$; the identification error e(k) calculated by $d(k)$ and $y(k)$ is provided to the LMS algorithm, and the coefficients of $\hat{H}_s(z)$ are adaptively updated. If the system converges, $\hat{H}_s(z)$ h can be used as an estimate of the secondary channel $H_s(z)$ h to FXLMS algorithm when the system is running long enough to reach a steady state.

3 The Characteristics of Engine Intake Noise

The noise of the engine induction system is the main noise source inside and outside the car, and it has a significant effect on the noise in the car. Induction noise is generated by the periodic opening and closing of the intake valve. When the intake valve opens, a pressure pulse is generated in the intake pipe. As the piston moves, this pressure wave is quickly damped; when the intake valve is closed At the same time, a pressure pulse is also generated, which is also damped and rapidly disappears. In a working cycle, there are two pressure pulses. The two pressure pulses occur periodically and form a periodic noise whose frequency is affected by the engine speed and expressed as:

$$f_i = \frac{n \cdot z \cdot k}{60\tau}(Hz) . \quad \textbf{(1)}$$

In the formula, k is the number of harmonics; 1, 2, 3..., n is the engine speed; z is the number of cylinders; z is the stroke coefficient; four-stroke τ = 2; two-stroke τ = 1.

From formula (1), the engine speed not only affects the noise frequency, but also has a large impact on the noise magnitude. For the same engine, the noise is linearly distributed with the speed change. For every 1000r/min increase in speed, the noise level increases by about 10 dB. Under normal circumstances, when the engine speed is 1000r/min, the inlet noise level is 73dB, and the noise level and speed satisfy:

$$SPL = \frac{n}{100} + 63 . \quad \textbf{(2)}$$

According to the definition of sound pressure level SPL, there are:

$$SPL = 20\lg(\frac{p_e}{p_{ref}}) . \quad \textbf{(3)}$$

In the formula, p_e is the sound pressure effective value; p_{ref} is the reference sound pressure, the value in the air is $2 \times 10^{-5} Pa$.

Formula (2) is substituted into Formula (1) and there is a relationship with speed n:

$$p_e = 2 \times 10^{\frac{n}{2000} - 1.85} . \quad \textbf{(4)}$$

According to the quantitative relationship between engine speed and noise frequency and sound pressure in formula (1) and formula (4), this paper makes use of engine speed signal to construct a reference signal of sound source, and simulates the effect of noise control.

4 Simulation

The noise level of the higher harmonics of the engine intake noise higher than the fourth order is lower and can be ignored [10]. The simulation is based on an inline four-cylinder and four-stroke automobile engine with a speed of 3000r/min. According to formula (1) and (4), construct reference signal:

$$\begin{aligned} x(n) &= 0.6\sin(2\pi f_1 t) + 0.4\sin(2\pi f_2 t) \\ &\quad + 0.2\sin(2\pi f_3 t) + 0.06\sin(2\pi f_4 t) \end{aligned} . \tag{5}$$

In the formula, f_1 = 100Hz, f_2 = 200Hz, f_3 = 300Hz, f_4 = 400Hz.

In the simulation process, the noise signal is a reference signal plus a random white noise with an amplitude of 0.2, ignoring the influence of other factors on the algorithm. The noise signal is:

$$P(n) = x(n) + 0.2rand(1, N) . \tag{6}$$

Set the primary and secondary acoustic path transfer functions in Fig. 1:

$$\begin{aligned} \mathrm{H}_1(z) &= 0.001 + 0.005z^{-1} - 0.005z^{-2} + 0.75z^{-3} + 0.5z^{-4} \\ &\quad -0.35z^{-5} - 0.4z^{-6} + 0.2z^{-7} + 0.4z^{-8} - 0.1z^{-9} \end{aligned} . \tag{7}$$

$$\mathrm{H}_2(z) = 0.01 + 0.01z^{-1} + 0.09z^{-2} - 0.01z^{-3} - 0.75z^{-4} . \tag{8}$$

The filter length L and convergence factor in the control algorithm can be used to evaluate the control system convergence, stability, and computational complexity. The convergence factor has the most obvious effect. The following simulation analysis of the noise control characteristics of the engine during operation and the parameters of the filter length and convergence factor are selected for simulation.

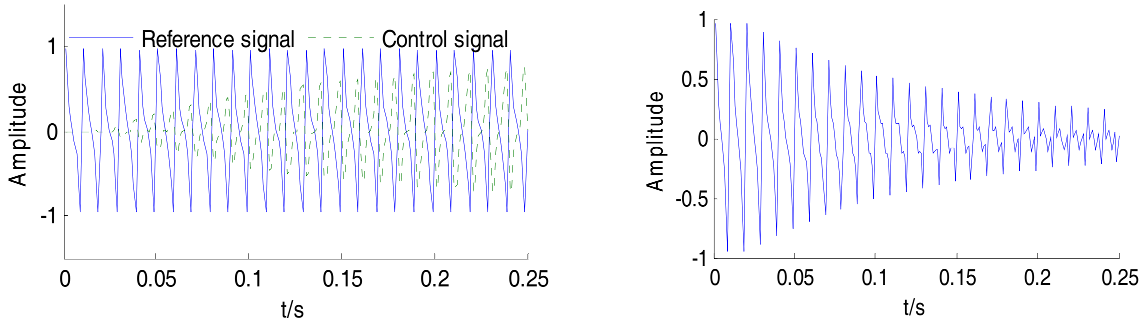
4.1 The Choice of Filter Length

To explore the effect of filter length L on system performance, choose different L values to investigate the error output of the system. Simulation parameters: The main controller convergence factor is 0.005. When L chooses 10, 20, and 30, the variation law of the reference signal and secondary signal amplitude with time and the error signal with time are discussed. The simulation results are shown in Fig. 3.

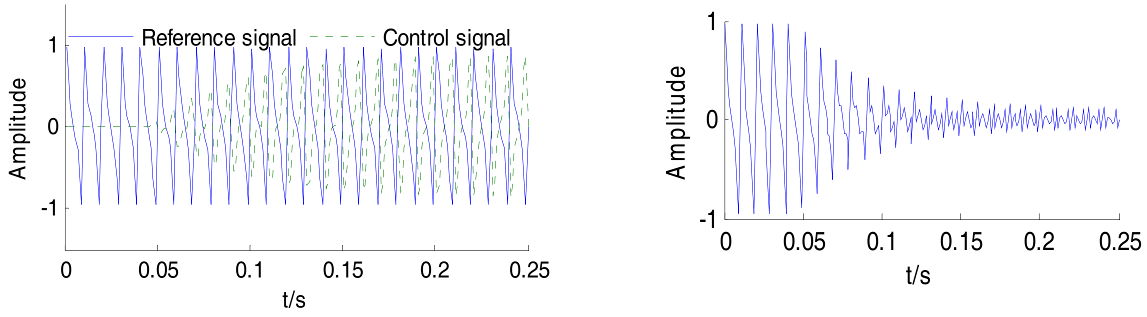
From Fig. 3, we can see that when L is small, the convergence speed is slow, and as L becomes larger, the system control accuracy is higher, the steady-state error is reduced, and the convergence speed is faster, but at the same time the calculation amount is increased, when the convergence factor is constant, When L is large enough, the system will diverge. Considering the cost of calculation and hardware implementation, the smaller L is selected when the convergence speed is faster and the steady-state error is smaller. Therefore, the filter length L is chosen to be 20 in this paper.

4.2 Effect of Convergence Factor

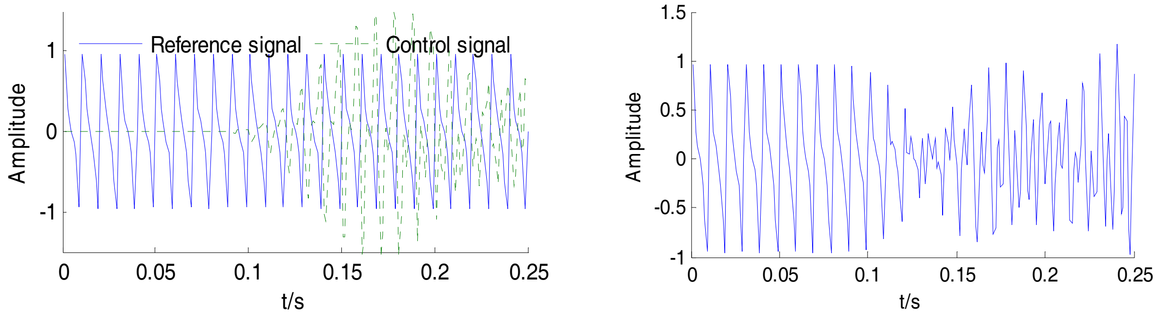
In order to investigate the influence of the convergence factor on the system performance, different values are selected to discuss the update status of the system output steady-state error and filter weights. Simulation parameters: L is 20, when the convergence factor of the main controller is 0.001, 0.01, 0.02, the variation law of the error signal with time and the change rule of the filter weight with time are discussed. The simulation results are shown in Fig. 4.



(a) Reference signal and secondary signal at L = 10 (b) Error signal at L = 10

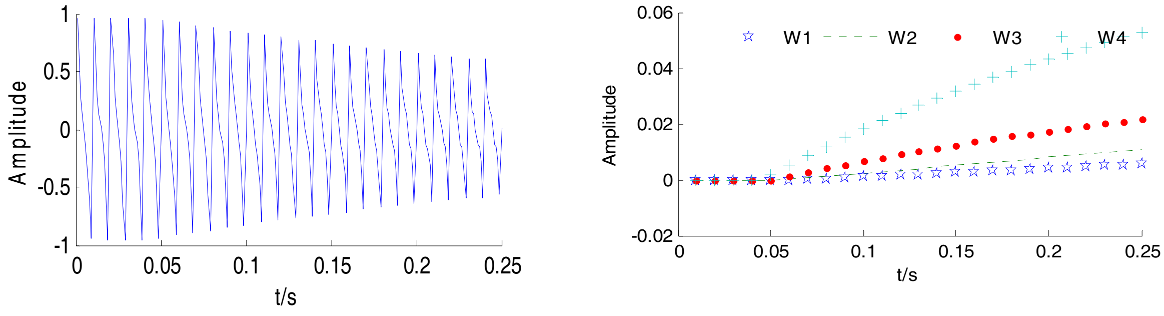


(c) Reference signal and secondary signal at L = 20 (d) Error signal at L = 20



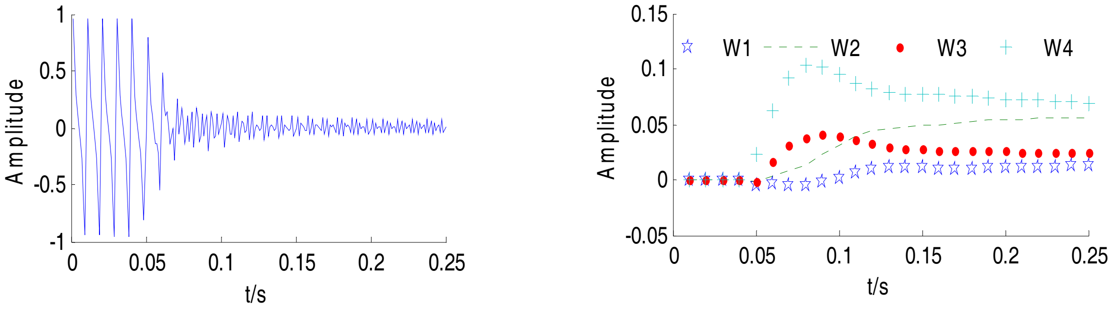
(e) Reference signal and secondary signal at L = 30 (f) Error signal at L = 30

Fig. 3. The variation of amplitude with time

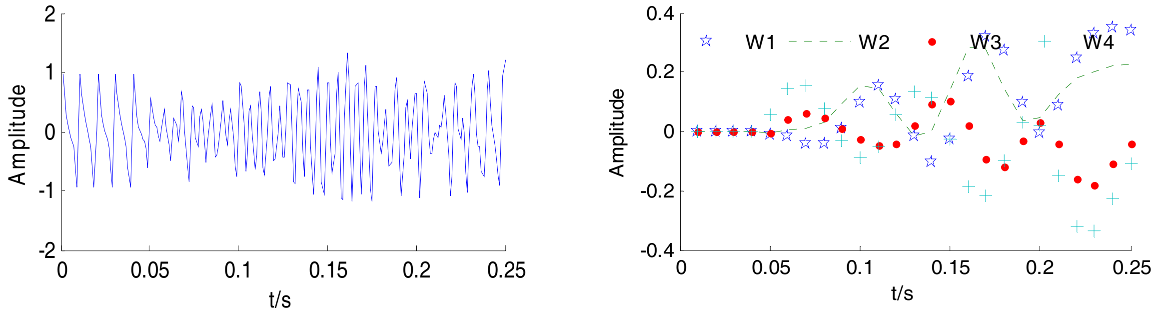


(a) Error signal at $\mu = 0.001$ (b) Filter weight at $\mu = 0.001$

Fig. 4. Variation of error and filter weights with time



(c) Error signal at $\mu = 0.01$ (d) Filter weight at $\mu = 0.01$



(e) Error signal at $\mu = 0.02$ (f) Filter weight at $\mu = 0.02$

Fig. 4. Variation of error and filter weights with time

From Fig. 4, we can see that when the convergence factor is 0.001, the convergence speed is slow, the filter weight tends to be stable, and the error signal is larger; when the convergence factor is 0.01, the convergence speed is fast, and the filter weight quickly reaches a steady state, and the error signal is small; when the convergence factor is 0.02, the system diverges and the filter weight does not reach a steady state. Therefore, as the convergence factor increases, the convergence speed becomes faster, and the calculation workload becomes smaller, but the convergence factor is not as large as possible, because when the large convergence factor is selected, the steady-state error of the system also becomes large; on the contrary, the selection of small Convergence factor can get smaller steady-state error, at the same time, it will lead to slower convergence speed and increase calculation workload. From this we can see that there is a contradiction between the convergence speed and the steady-state error of the system when the convergence factor is fixed. Based on the above factors, the engine speed set according to this article is selected as 0.01.

In order to evaluate the noise reduction effect, calculate the time domain average power values of the noise signal and the error signal, denoted as P_1 、P_2. Thus, the amount of noise reduction can be expressed as:

$$\Delta E = 20\lg\frac{P_1}{P_2}. \tag{9}$$

In this simulation, the set engine speed is 3000r/min, L is selected as 20, μ is 0.01, and the noise reduction value is calculated as 24.8 according to formula (9). Similarly, the values of L and u under different rotation speeds are calculated, and the noise reduction values under different rotation speeds are obtained, as shown in Table 1.

Table 1. Noise reduction at different engine speeds

$n / r \cdot \min^{-1}$	u	ΔE /dB
2400	6×10^{-2}	25.4
3000	1×10^{-2}	24.8
3600	1.8×10^{-3}	24.3
4200	2.9×10^{-4}	20.9
4800	5×10^{-5}	18.6
5400	0.9×10^{-5}	17.6
6000	1.6×10^{-6}	15.9

From Table 1, it can be seen that L=20, and for every 600 increase in rotation speed, the convergence factor is reduced by approximately 6 times. As the rotational speed increases, the amount of noise reduction is smaller, so the noise reduction effect at low engine speeds is better than at high rotational speeds.

Acknowledgements

The filter length L and the convergence factor μ have an important influence on the control system performance. Choosing the appropriate L and μ can make the system get faster convergence speed and smaller steady-state error.

The noise control system has a significant noise reduction effect on the engine's low-speed noise, and each speed can reduce the noise by more than 15dB.

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