

Study on Active Noise Control of Blower in Fuel Cell Vehicle under Transient Conditions

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ABSTRACT

Blower is one of the main noise sources of fuel cell vehicle. In this paper, a narrowband active noise control (ANC) model is established based on adaptive notch filter (ANF) to control the high-frequency noise produced by the blower. Under transient conditions, in order to reduce the frequency mismatch (FM) of ANC for blower, a new Frequency Mismatch Filtered-Error Least Mean Square algorithm (FM-FELMS) is proposed to attenuate blower noise under transient conditions. According to the theoretical analysis and simulation, the proposed algorithm has an excellent noise reduction performance at relatively high blower speed. While for the low speed working condition, the Normalized Least Mean Square (NLMS) algorithm is applied to attenuate noise. The two algorithms could be jointly utilized to control the blower noise actively.

KEYWORDS: Active noise control, Frequency mismatch, FM-FELMS algorithm, Transient condition, Blower

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INTRODUCTION

The blower used to provide the air for fuel cell is one of the main noise sources of fuel cell vehicle [1]. And the air-inlet pipeline was the main radiation channel of aerodynamic noise generated by the blower. In this paper, the ANC method is applied to attenuate the blower noise at the air-inlet pipeline.

ANC in actual application reveals that the FM [2] degenerates the performance of noise control [3]. In 2005, Yegui Xiao proposed a new LMS-Based Fourier Analyzer which was used to attenuate noise in low frequency of cutting machine in view of the FM compensation problem [4]. Xu Sun proposed a new algorithm to compensate for the FM. The simulation results are provided to demonstrate the poor effectiveness of the proposed algorithm at a frequency of about 1000 Hz [5]. In 2010, Hyeon-Jin Jeon studied narrowband ANC system in the presence of FM, the research focused on attenuating noise in low frequency (200Hz) under two steady conditions [6]. In 2012, J.H.PARK and S.K.LEE optimized the ANC system by taking the acoustical feedback of the secondary into account. The new system was applied to attenuate the noise of engine. The result showed the convergence property of the improved algorithm is great [7]. All above mentioned scholars studied the ANC in low frequency under steady conditions [8, 9, 10], and only a few took the FM into account. But the ANC system under transient conditions, especially in high frequency domain has received much less attention. To the authors' knowledge, as for the ANC system to attenuate the noise of the blower under transient conditions has not been reported.

The harmonic noise frequency of rotating power machine is proportional to the blower speed, which makes it significant to update the noise frequency when the ANC system is applied under transient conditions. It has been shown that the performance of the existing algorithms degenerated significantly due to the existence of the FM. To compensate for this degeneration, a new algorithm-FM-FELMS is proposed in this paper. When the proposed algorithm is applied for accelerating condition in normal revolution (2200rpm-3800rpm), it has an excellent acoustic performance. To extend the application scope of ANC under transient conditions, the authors propose a new control strategy of combining the proposed algorithm with the NLMS algorithm.

ANALYSIS ON BLOWER NOISE CHARACTERISTICS

In fuel cell vehicle, the air-outlet and air-inlet of the blower connect to the fuel cell stacks and air, respectively. According to Kang Q [11], the air-inlet pipeline is the main radiation channel of aerodynamic noise generated by the blower. Fig.1 is the noise waterfall when the blower speed ranges from 1000rpm to 3800rpm. The muffler is mounted on the air-outlet pipeline.

Fig.1 shows that the peak value frequency ranges from 900Hz to 3500Hz under transient conditions. Above 2200rpm, with the increase of rotational speed, the peak noise increases rapidly, the corresponding frequency ranges from 2000Hz to 3500Hz. Taking one steady condition for analysis, the noise spectrum of the blower speed of 3400 rpm is shown as Fig.2.

The harmonic frequency of rotational noise generated by the blower is given by

$$f_i = \frac{n}{60} \times i, \quad i = 1, 2, 3, \dots \quad (1)$$

Here, n is the rotational speed of the blower. When $n=3400\text{rpm}$, $i=1$, the calculated fundamental frequency is 56.7Hz . The peak value frequencies lie in 3120Hz and 6240Hz , corresponding to the 55th and 110th harmonic frequency. The noise of 55th harmonic frequency contributed much more than the others, as much as 96.73dB .

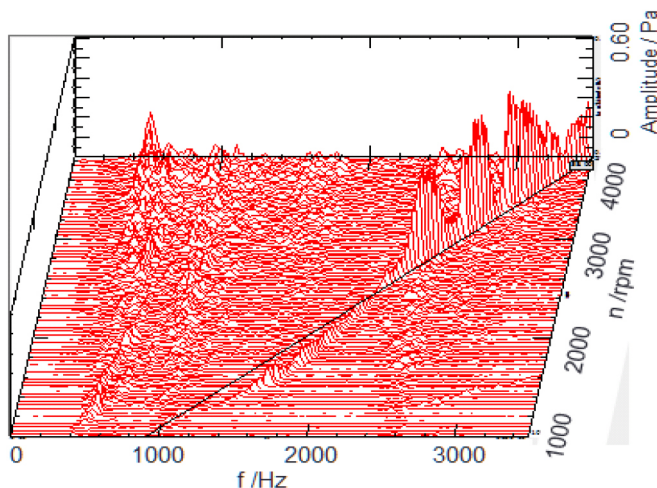


Fig.1. Blower noise waterfall figure under transient conditions

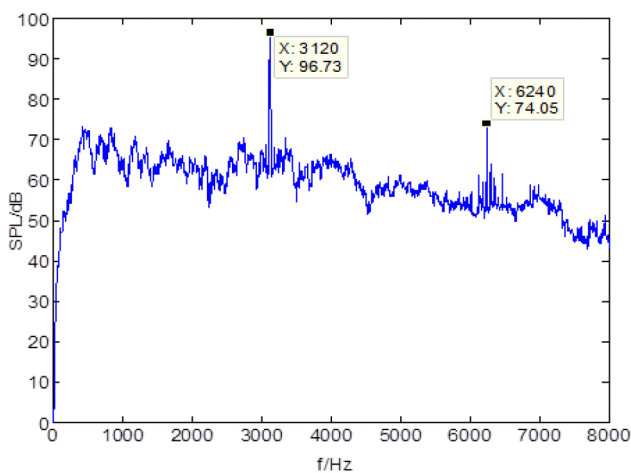


Fig.2. Noise spectrum of blower under steady condition with the rotational speed of 3400rpm

In addition, the authors analyze the peak value frequencies of different rotational speeds. According to the result, the 55th harmonic frequency is the main noise frequency under the steady rotational condition. According to the analysis above, the attenuation of 55th harmonic frequency noise is apparently critical to reduce noise generated by the blower.

The cut-off frequency (Hz) of a circular cross-section pipe is given by

$$f_c = 1.84 \frac{c_0}{2\pi a} \quad (2)$$

Here, a is the radius of the circular cross-section pipe. c_0 is the sound velocity in the air. When $a=26.5\text{ mm}$, substituting it into equation (2) leads to

$$f_c = 1.84 \times \frac{340}{2\pi \times \frac{26.5}{1000}} = 3757.36\text{Hz}$$

Since the common rotational speed of the blower ranges from 1400rpm to 3800rpm , the corresponding frequencies range from 1300Hz to 3600Hz , lower than 3757.36 Hz . The plane sound wave propagation in the pipeline is verified accordingly.

The narrowband ANC algorithm based on ANF can attenuate noise at the given reference signal frequency. In actual application, the frequency of reference signal differs from the frequency of the noise signal inevitably. This difference is referred to as FM which greatly degenerate the performance of the narrowband ANC algorithm. Especially under transient conditions, the noise signal always varies with rotational speed. The degeneration caused by FM can't be ignored. However, the algorithms existed can't satisfy the demands of good acoustic performance and sufficient stability in the high-frequency domain due to FM.

Analysis on FM-FELMS

As the algorithms already existed can't track the frequency of noise signal or guarantee the control effect in high frequency under transient conditions. A new algorithm called FM-FELMS is proposed which is based on ANF and FM compensation algorithm. The simulation model is shown as Fig.3.

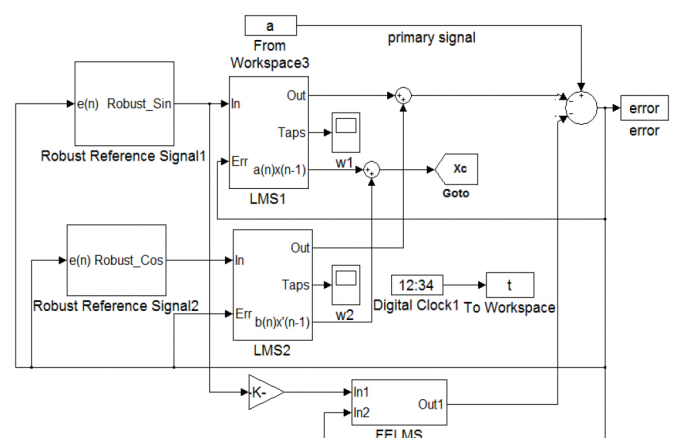


Fig.3. the simulation model of FM-FELMS

FM-FELMS algorithm is made up of two parts: FM compensation algorithm and FELMS algorithm. FM compensation algorithm includes ANF and the part of FM removal, the latter is responsible to update the reference signal frequency according to the residual noise signal. The signal after updating is the input of the ANF which updates the amplitude and phase of the signal.

attenuates the noise at the input frequency, improving the noise attenuation performance of the system. This section will analyze the two parts from the views of theory and simulation.

Analysis on FM compensation algorithm

On the premise of the steepest descent nature and effectiveness of the algorithm, FM compensation algorithm is made up of two parts: ANF and FM removal part. The structure of ANF is shown as Fig.4 [14]. The reference signal can be synthesized by the narrowband ANC system [12-13] based on ANF. The filter of 2 orders can guarantee the good convergence property, making it appropriate for attenuating the noise of 55th harmonic frequency in fuel cell vehicle. Here the reference signal $x_0(n)$ is:

$$x_0(n) = A \sin(\omega_0 n) \quad (3)$$

$x_0(n)$ is the result of $x_0(n)$ shifting 90° in phase:

$$x_1(n) = A \cos(\omega_0 n) \quad (4)$$

Updating the reference signal $x_0(n)$, $x_1(n)$ by weight coefficient $w_0(n)$, $w_1(n)$. The output is:

$$y(n) = w_0(n)x_0(n) + w_1(n)x_1(n) \quad (5)$$

The error signal is:

$$e(n) = d(n) - y(n) \quad (6)$$

Here LMS algorithm is used to update the weight coefficient:

$$w_l(n+1) = w_l(n) + \mu x_l(n)e(n), l = 0, 1$$

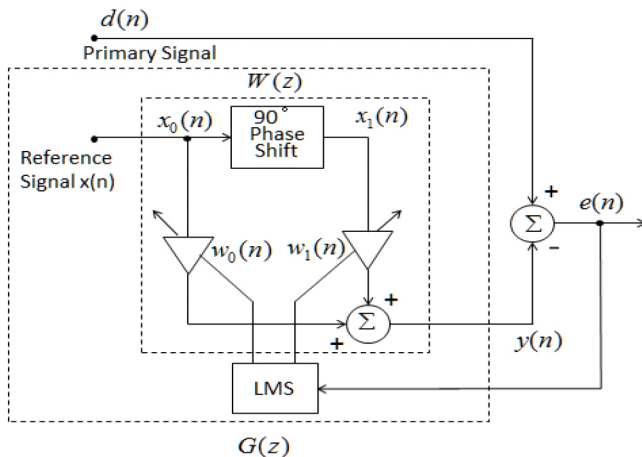


Fig.4. The block diagram of ANF [14]

The transfer function from the primary signal $d(n)$ to the error signal $e(n)$ is:

$$H(z) = \frac{E(z)}{D(z)} = \frac{E(z)}{E(z) + Y(z)} = \frac{z^2 - 2z \cos \omega_0 + 1}{z^2 - (2 - \mu A^2)z \cos \omega_0 + 1 - \mu A^2} \quad (7)$$

The block diagram of FM compensation algorithm [15] is shown as Fig.5[4].

Here, the reference signals are:

$$x_{a_i}(n) = \cos(w_i(n)n) \quad (8)$$

$$x_{b_i}(n) = \sin(w_i(n)n) \quad (9)$$

$x_{a_i}(n)$, $x_{b_i}(n)$ are in the following recursive fashion:

$$\begin{aligned} x_{a_i}(n) &= -c_i(n)x_{a_i}(n-1) - x_{a_i}(n-2), \quad n \geq 2 \\ x_{a_i}(0) &= 1, \quad x_{a_i}(1) = \cos(w_i(0)) \end{aligned} \quad (10)$$

$$\begin{aligned} x_{b_i}(n) &= -c_i(n)x_{b_i}(n-1) - x_{b_i}(n-2), \quad n \geq 2 \\ x_{b_i}(0) &= 0, \quad x_{b_i}(1) = \sin(w_i(0)) \end{aligned} \quad (11)$$

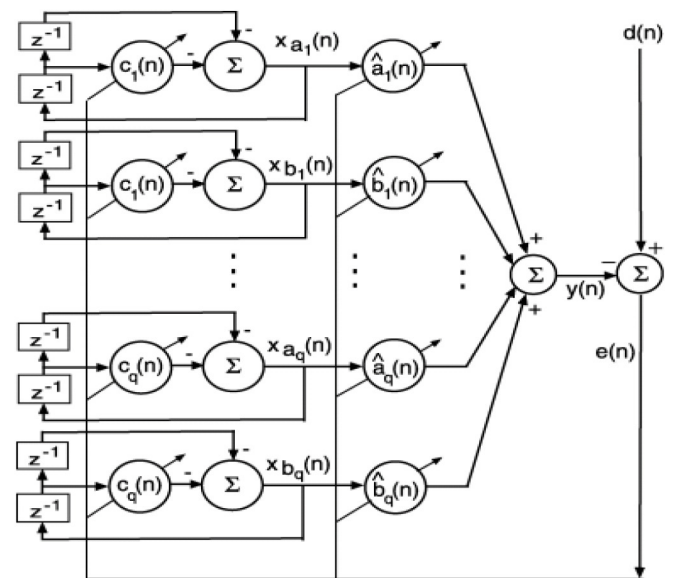


Fig. 5. The block diagram of FM compensation algorithm [4]

The circular frequency of reference signal is updated indirectly by the gradual iteration of the reference signals $x_{a_i}(n)$ and $x_{b_i}(n)$.

Here the renewing coefficient $c_i(n)$ of $x_{a_i}(n)$ and $x_{b_i}(n)$ are: