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Active Control of Restricted Space Noise in Deep Well Using FXLMS Adaptive Control Algorithm

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Restricted spatial noise in deep wells does great harm to the human body, and it needs to be effectively controlled. This study explores the application of the Filtered-XLeast Mean Square (FXLMS) algorithm to deep well active noise control (ANC). Firstly, the FXLMS algorithm is briefly introduced, and then the simulation method of the FXLMS algorithm in Simulink environment was analyzed. In the experimental analysis, the size of the filter and convergence factor of the FXLMS algorithm were determined. Then the algorithm was used to control the simulated restricted space noise of deep wells. The results showed that the noise reduction level was better when the filter order was 30, and the calculation amount was small; when the convergence factor was 0.03, the convergence speed was high, and the stability was good. The energy value of the noise signal after control of the deep well noise was greatly reduced, which showed that the algorithm had good control effect. The results of this study prove the effectiveness of FXLMS adaptive control algorithm in ANC and makes a contributions to the effective control of restricted space noise in deep wells.

Keywords: filtered-x least mean square, deep well noise, active noise control, simulation experiment

1. INTRODUCTION

Noise is a harmful sound to the human body. When working in the restricted space of deep wells, the use of a large number of mechanical equipment will produce a lot of noise and this is not conducive to the physical health and normal work of staff. It is a major occupational hazard. Effectively control of noise has attracted wide attention in today's society. Traditional noise control mainly uses sound-absorbing materials for sound insulation and absorption, but design is difficult and the effect of low-frequency noise generally remain. Active noise control (ANC) uses an anti-noise with the same noise size but opposite phase to eliminate or weaken noise, which shows excellent performance in noise control [1]. It has been applied in various systems [2, 3]. The control algorithm is the core part of ANC, which is directly related to the effect of noise control and has been widely studied by researchers. Chen et al. [4] studied the noise control of polyvinyl chloride pipes, proposed a single-channel feed forward algorithm based on feedback neutralization to realize ANC, proved the reliability of the algorithm by experiments on channel noise and white noise, and found that its noise reduction to white noise could be 20 dB. Lu et al. [5] designed a filtered-x recursive maximum entropy (FXRMC) algorithm based on maximum entropy criterion (MCC) and proved its excellent performance in various noise environments through simulation experiments. Zhou et al. [6] implemented ANC using a simultaneous perturbation stochastic approximation (SPSA) algorithm based on functional link artificial neural network (FLANN) and found through experiment that the algorithm could eliminate the need for secondary path modeling of ANC system and had good noise control performance. Qiu et al. [7] proposed a control algorithm based on discrete wavelet transform (DWT), realized DWT using

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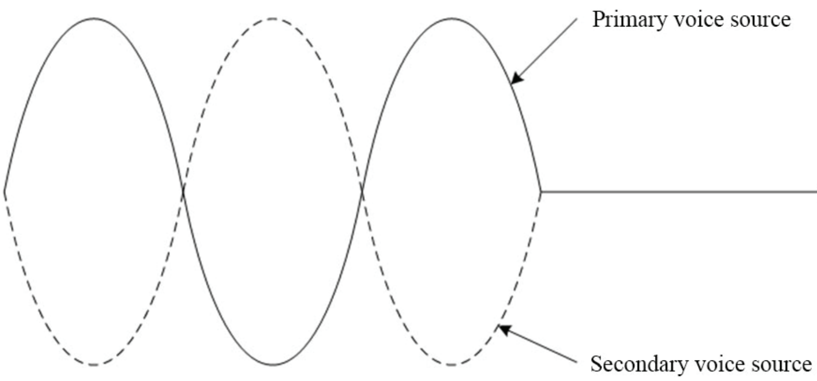

Figure 1 Principle of ANC.

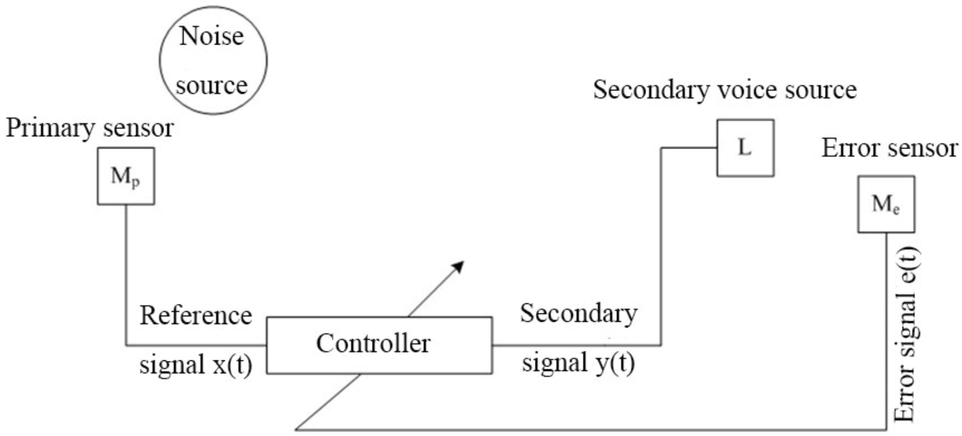

Figure 2 The structure of the feed forward ANC system.

Mallat pyramid algorithm, and found through experiments that the algorithm had excellent convergence performance and prominent time-frequency characteristics. In this study, the application of the Filtered-XLeast Mean Square (FXLMS) algorithm in ANC was studied. The algorithm was simulated using Simulink. Then the filter order and convergence factor were determined. The reliability of the algorithm was demonstrated for control of simulated deep well noise. This work makes some contributions to the further application of FXLMS algorithm in ANC field and is also conducive to the promotion and application of the algorithm in deep well restricted space noise control and the reduction of the impact on the mental and physical health and normal work of workers in deep wells.

2. ACTIVE NOISE CONTROL (ANC)

The working principle of ANC is shown in Figure 1. A quadratic sound equal to the amplitude of the noise source and opposite to the phase is generated and superimposed with the original noise to realize noise reduction.

ANC can be divided into feed forward and feedback. As the stability of the feedback ANC system has some problems, feed forward ANC system [8] is widely used in practice. Its structure is shown in Figure 2.

As shown in Figure 2, M_p acquires sound signal from noise source then converts it into electrical signal to obtain x(t). x(t) is input into the controller. The algorithm outputs an electric signal to make L output y(t) which offsets. The collected e(t) is sent to the controller through M_e, so that the controller can adjust parameters continuously to reduce errors, thus realizing the control of noise.

The control algorithm is the most critical part of the controller, which directly affects the effectiveness of the final noise control. This paper mainly studies the FXLMS algorithm.

3. FXLMS ALGORITHM

3.1 Algorithmic Principle

FXLMS algorithm has fast convergence speed and good error control effect. It is widely used in engineering [9]. The principle of FXLMS algorithm is shown in Figure 3.

The filter order is supposed as L. The weight coefficient of the transversal filter at time t can be expressed as:

$$W(t) = [w_1(t), w_2(t), \cdots, w_L(t)],$$

and the reference signal can be expressed as:

$$X(t) = [x_1(t), x_2(t), \cdots x_n(t)].$$

The relationship between the signals is:

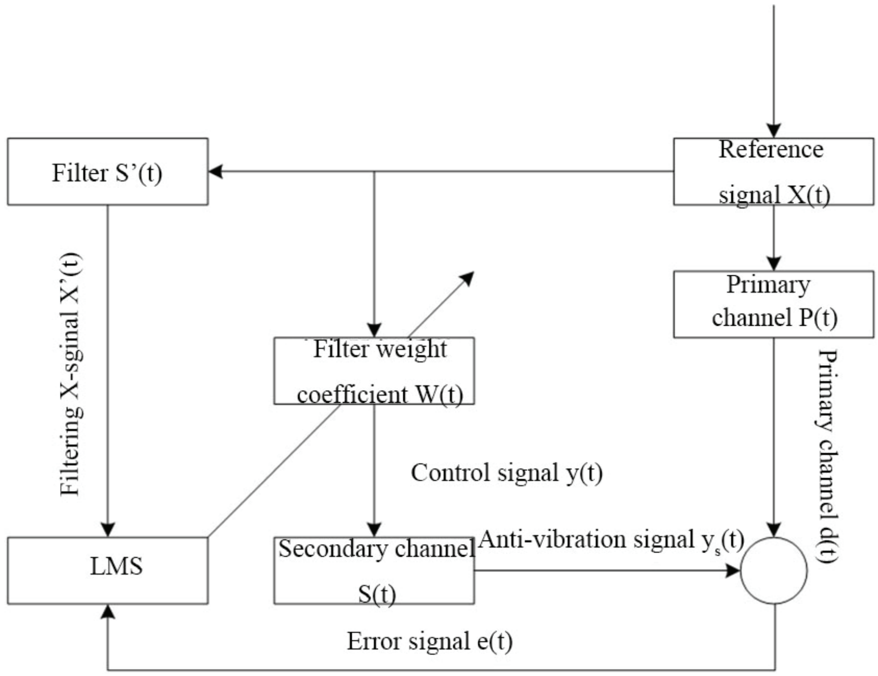

Figure 3 The principle of FXLMS algorithm.

$$d(t) = X(t) \times P(t)$$
$$y_s(t) = y(t) \times S(t)$$
$$y(t) = \sum_{l=0}^{L} w_l(t)\, x(t-l+1)$$

The output anti-vibration signal at time $t$can be expressed as:

$$y_s(t) = \sum_{l=1}^{L} w_l(n)\, x'(n-l+1).$$

The matrix form can be written as

$$y_s(t) = X'^T(t)\, W(t),$$
$$X'(t) = X(t) \times S'(t),$$
$$e(t) = d(t) - y_s(t) = d(t) - X'^T(t)\, W(t).$$

Objective function is expressed as $J(t)$. The LMS algorithm is used to minimize the numerical value:

$$J(t) = E\left\{e^2(t)\right\}.$$

Suppose that the autocorrelation matrix of

$$X'(n) \text{ is } R = E\left\{X'(t)\, X'^T(t)\right\},$$

and the cross correlation matrix of $X'(t)$ and $d(t)$ is

$$P = E\left\{d(t)\, X'(t)\right\}.$$

$J(t)$ can be written as

$$J(t) = E\left\{d^2(t)\right\} - 2W^T P + W^T R W,$$

and the optimal solution of W can be obtained through derivation. Then the minimum mean square error is

$$J_{\min} = E\left\{e^2(t)\right\}, \quad \nabla(t) = -2E\left[e(t)\, X'(t)\right].$$

The expression of the weight coefficient can be written as

$$W(t+1) = W(t) + 2\mu e(t)\, X'(t),$$

where μ stands for convergence factor, $0 < \mu < \frac{1}{\lambda_{\max}}$, and $\lambda_{\max}$ stands for the maximum characteristic value of matrix R.

Using the cross correlation matrix of $X'(t)$ and $d(t)$ which is $P = E\left\{d(t)\, X'(t)\right\}$. $J(t)$ can be written as $J(t) = E\left\{d^2(t)\right\} - 2W^T P + W^T R W$, and the optimal solution of W can be obtained through derivation. Then the minimum mean square error is

$$J_{\min} = E\left\{e^2(t)\right\}, \quad \nabla(t) = -2E\left[e(t)\, X'(t)\right].$$

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3.2 Simulink Simulation

Because of the different structure of the algorithms, the FXLMS algorithm cannot be implemented by the LMS filter module. In order to simulate the FXLMS algorithm in the Simulink environment, Level-2S function is adopted. The specific steps are as follows:

(1) Setup function body is used to initialize the module, and the input and output ports are set (including the attributes such as dimension and complexity of the ports).

(2) The validity of μ value is tested using CheckPrms function body.

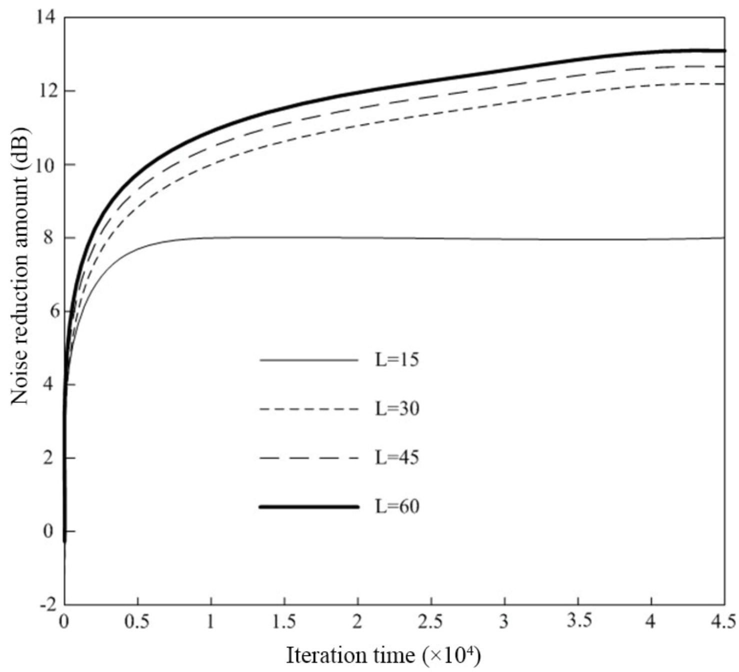

Figure 4 Noise reduction level under different orders.

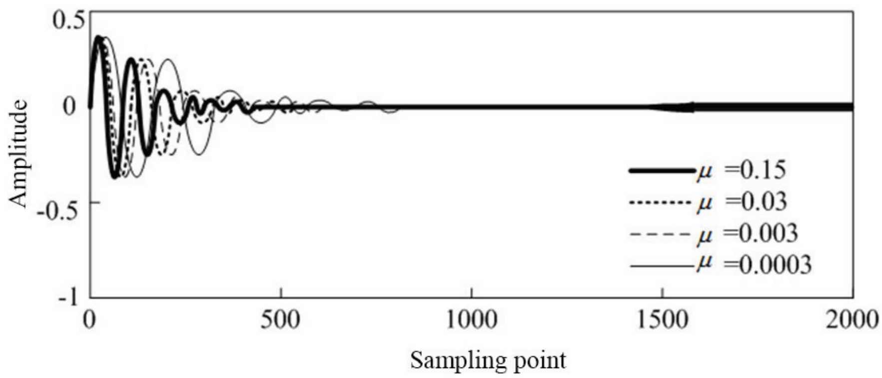

Figure 5 The convergence condition under different values of μ.

(3) Two Dwork vectors are established using DoPost-PropSetup function body as $X(n)$ and w

(4) The initial value of Dwork to 0 is set as 0 usingStart function body.

(5) The weight updating and calculation results of FXLMS algorithm are output using Output function body.

4. CASE STUDY

In order to verify the role of FXLMS algorithm in the noise control of restricted space in deep wells, the algorithm was simulated in Simulink according to the method in the last section. FIR filters were used in primary and secondary channels. The order of filters is set as 15, 30, 45 and 60, and the convergence factors were set as 0.15, 0.03, 0.003 and 0.0003.

The convergence factor is positioned at 0.03, mixed noise at 50Hz, 100Hz, 200Hz and 400Hz were taken as input signals. The noise attenuation level under different orders are shown in Figure 4.

It was found from Figure 4 that the amount of noise reduction increased gradually with the increase of the order of the filter, which indicated that the level of noise reduction increased gradually, and the difference between the order of 30, 45 and 60 was small. As the order of the filter increases, it will increase the amount of calculation in the algorithm. The order of the filter is set as 30 in this paper.

When the order of the filter was set as 30, the convergence of the ANC system under different convergence factors is shown in Figure 5.

As can be seen from Figure 5, the larger the value of μ, the faster the convergence rate of the system, but when the value was large (μ= 0.15), the stability of the system decreased and divergence occurred. Therefore the value of μ was set as 0.03.

After the values of L and μ were determined, three sinusoidal signals of 80Hz, 95Hz and 110Hz were superimposed with white Gaussian noise to simulate deep well noise. The FXLMS algorithm designed in this study was used to control the deep well noise. The frequency domain of the noise before and after control is shown in Figure 6.

The solid line in Figure 6 represents the noise signal before control and the dotted line represents the noise signal after control. It was found that the energy value of the noise was

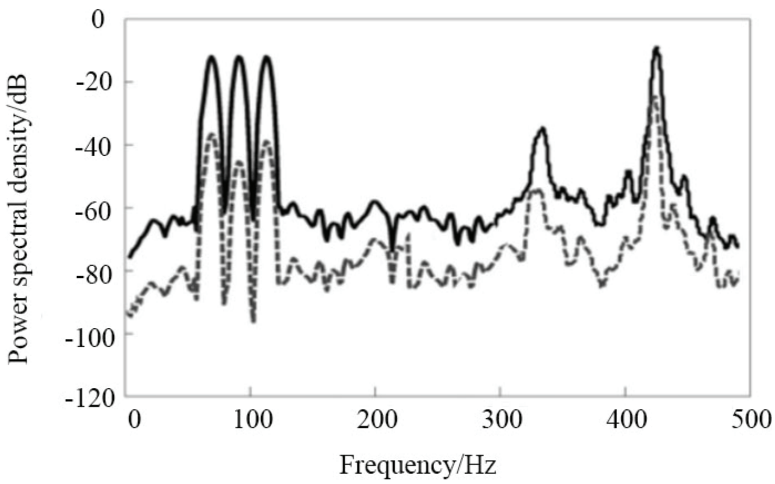

Figure 6 Noise control results.

greatly reduced after control by FXLMS algorithm, which was clearly different from the original noise value. It showed that the method was effective in controlling deep well noise.

5. DISCUSSION

People occupy an important position in production activities, and physiological or psychological factors such as fatigue, distraction and emotional fluctuations will directly affect the quality of people's work and result in a significant impact on production. With the improvement of mechanical level and the deepening of mining depth, the problem of restricted space in a deep mine has been of considerable concern. In the restricted space of deep wells, temperature, humidity, noise, dust, harmful gas and so on will have an impact on human physiological health and work efficiency. Noise is one of the main hazards in deep well restricted space operation [10]. Its main effects on the human body are: (1) it can affect the auditory system [11]: continuous high-intensity noise can cause hearing sensitivity decline, hearing fatigue, hearing threshold change, and even deafness [12]; (2) it can affect the nervous system [13]: noise can cause nervous dysfunction, headache and fatigue, insomnia and so on and will destroy the sympathetic nerve movement, leading to changes in blood pressure [14], vasospasm and so on; (3) it will affect the digestive system: noise can cause nausea, indigestion and loss of appetite and other diseases such as gastric ulcer in severe cases. In the restricted space of deep wells, there are many noise sources with strong intensity, long duration and high sound pressure. It is of great significance to find effective methods to control the noise in order to maintain the physical and mental health of staff. In addition, the existence of noise will accelerate the aging of industrial equipment, shorten the service life of equipment, and lead to the decline of equipment accuracy. Therefore, noise control has an important value for maintaining the reliability of engineering equipment.

FXLMS is an effective ANC algorithm [15]. It is an improvement over the LMS algorithm. The error of the LMS algorithm is corrected by secondary path modeling. It has an important effect in low frequency noise control, higher stability and better noise control performance. FXLMS has a good application in noise control of pipelines, automobiles and other fields [16]. In this study, the application of FXLMS algorithm in deep well restricted space noise control was studied. The principle of FXLMS algorithm was analyzed, and its simulation in Simulink environment was illustrated. Then, through the analysis of an example, it was found that the size of filter and convergence factor had some influence on the performance of the algorithm. It was found from Figure 4 that the larger the filter order, the larger is the noise reduction amount and the better the noise reduction performance of the system, but at the same time, the amount of calculation was also increased. In order to ensure the balance between the noise reduction performance and the amount of calculation, the filter order was set as 30 in this paper. It was found from Figure 5 that the larger the convergence factor of the algorithm, the higher the convergence speed of the algorithm, but when the convergence factor was too large ($\mu = 0.15$), the divergence of the system occurred, which indicated that the stability of the system decreased. Therefore, after considering the convergence speed and stability of the system, the convergence factor was set as 0.03. Finally, FXLMS algorithm was used to control the simulated deep well noise. It was found from Figure 6 that the noise signals before and after the control were significantly different; after it was controlled by the FXLMS algorithm, the energy value of noise was greatly reduced, achieving the significant effect of noise reduction. It showed that the algorithm was effective in ANC.

In this paper, although some achievements have been made in the application of FXLMS algorithm in ANC, there are still many shortcomings. In the next step, it is necessary to further reduce the complexity of the algorithm and improve the speed of noise reduction in order to further improve the effect of noise control.

6. CONCLUSION

This study focuses on the application of FXLMS algorithm in ANC of restricted space noise in deep wells. The simulation of FXLMS algorithm in the Simulink environment was analyzed. The optimal filter order and convergence factor were obtained through experiments. The reliability of FXLMS algorithm was demonstrated in the simulated deep well's noise control, which provides support for the application and popularization of FXLMS algorithm in the control of restricted space noise in deep wells, which is beneficial to the further development of ANC field.

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