Study on Active Vibration Isolation Control for Electromagnetic Floating Raft Platform

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Abstract

The normalized FLMS algorithm makes the convergence coefficient vary with time, which makes the adaptive process achieve a compromise between the convergence coefficient and the steady state error and overcomes the problem that the convergence factor is difficult to select, caused by that the power of the reference signal cannot be accurately estimated or vary too fast with time. In this paper, the magnetic suspension floating raft vibration isolation system acting as the object, the FIR filter being introduced as a feed-forward link, and the mean square error of systematic deviation operating as the performance indicators, the normalized FLMS algorithm is used for self-optimization to obtain the optimal controller parameters. The simulation results show that the normalized FLMS algorithm has better effect over convergence speed and vibration isolation compared with the ordinary FLMS algorithm. So it was applied to active control system of the magnetic suspension floating raft vibration isolation, and achieved better effect.

Keywords: Normalized FLMS algorithm; Floating Raft Platform; Active vibration

1 Introduction

Mute capability of the submarine is an important indicator of its combat capacity. Vibration isolation technology can effectively reduce the mechanical vibration and improve the mute capability of the submarine. Tuning effect, quality effect and mixed arrived effect of the floating raft system can not only reduce the radiated noise, but also weaken high-frequency signals of the vibration obviously. Therefore, the floating raft system is widely used in submarines [1]. However, as a passive vibration isolation system, it has some amplification to the vibration which is less than or equal to the natural frequency of the system. The active vibration isolation system can dynamically adjust its support parameters according to control law, which can meet the needs of vibration isolation in low frequency and near the resonant frequency that the passive vibration isolation system cannot achieve. Therefore, active and passive combined vibration isolation technology is regarded as a hotspot in current researches. Magnetic suspension vibration isolation technology has some useful characteristics, such as non-contact, no lubrication and long life-span, so it is of great significance to apply the magnetic suspension vibration isolator to the floating raft system.

Control methods of the magnetic suspension vibration isolation system have become the core content of current researches. As it has the advantage that the stability is better than the feedback system, the feed-forward control system has been widely used in adaptive filtering [2], especially in areas of active vibration isolation. The control

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effect of the stable, narrowband and uniform broadband vibration is better if the feed-forward control method is used. As the magnetic suspension floating raft vibration isolation system has problems of much interference and the convergence speed of ordinary FLMS algorithm is slow, the isolation effect is poor. [3] In this paper, the magnetic suspension floating raft vibration isolation system acting as the object, the FIR filter being introduced as a feed-forward link and the mean square error of systematic deviation acting as the performance indicators, the normalized FLMS algorithm is used for self-optimization to obtain the optimal controller parameters.

2 Magnetic vibration isolation floating raft bench

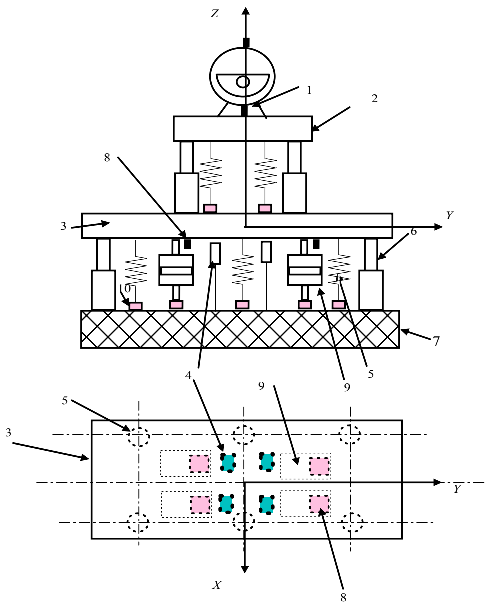


Fig. 1 Magnetic vibration isolation floating raft bench

Magnetic suspension floating raft active vibration isolation bench consists of the following components: 1 Incentives motor, 2 base of the motor, 3 raft frame, 4 vibration isolator,5 springs, 6 rigid stent, 7 base, 8 acceleration sensors, 9 displacement sensors, 10 force sensor. Incentives motor and base of the motor are connected rigidly to make up the isolation quality. The isolation quality and raft frame are connected by a spring, and four force sensors are connected in the middle to measure signals of the transmit force. Four magnetic suspension vibration isolators and six springs are installed under the raft frame. The acceleration sensors are distributed around the isolators to measure acceleration signals of the raft frame. Six springs and four displacement sensors are distributed between the raft frame and rigid base to measure displacement signal of the raft frame. The platform has three degrees of freedom, a Z-axis vibration, rotation of the X-axis and Y-axis direction.

Wiener filter, used in this paper, is only suitable for stationary random process and time-invariant system. After the 800mV, 1000mV and 1250mV smooth random signals are inputted to the system, the acceleration signals are collected to identify dynamic systemic model of the system. Under different voltage, the systemic models are of high consistency. Experimental results show that it is a time-invariant system, which is in line with the requirements of the Wiener filter.

3 The Normalized FLMS algorithm

In the FLMS algorithm, convergence coefficient is related to the length of the filter and the power of the reference signal. When the external disturbance is too strong, the power of the reference signal can't be accurately estimated, or it changes fast with time, which leads to that the convergence coefficient is difficult to select. The normalized algorithm makes the convergence coefficient vary with time, no longer being fixed, to get balance between convergence rate and steady-state error. At the same time, it also makes the convergence time independent of the reference signal power. In this paper, the weight vector iteration is set with the variable step-size convergence coefficient [4].

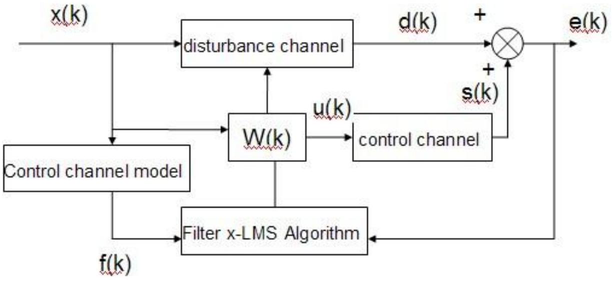


Fig. 2 Based on adaptive FIR filter feed-forward control system diagram

x (k) is the reference signal. u(k) is the output signal of the feed-forward controller. A FIR filter is set between x(k) and u(k). The effect of the interference signal is counteracted by adaptively updating its weight coefficient matrix W(k). y(k) is got after u(k) passes the control channel. The interference signal d(k) is the signal that the reference signal which passes the disturbance channel adds at the output point of the system. e(k) is the output signal of the system.

Adaptive process of the adaptive filter feed-forward control is a process which is self-optimizing for weight coefficient matrix of FIR filter. In this paper, the LMS algorithm which self-adaptively updates weight coefficient matrix of the FIR filter using gradient descent is selected [5]. The general gradient descent, as follows:

$$W(k+1)=W(k)-\mu\Delta W(k) \tag{1}$$

△W(K) is performance index, J(k) is gradient of weight coefficient matrix which is got at present. Mean-square deviation of system error is select to be performance index.

$$J(k)\approx e^2(k)=\left(d(k)+W^T(k)x(k)\right)^2 \tag{2}$$

The equation of weight vector iteration is

$$W(n+1)=W(n)-2\mu(n)e(n)r(n) \tag{3}$$

$\mu(n)$ is time-varying convergence coefficient. The formulas is

$$\mu(n)=\frac{2\mu_0}{L\hat{P}_x(n)} \tag{4}$$

μ_0 is the normalized convergence coefficient, the value range is between 0 and 1; L is horizontal length filter; $\hat{P}_x(n)$ is estimated value which is input power of the reference signal at n time, using sliding rectangular window method.

$$\hat{P}_x(n)=\frac{1}{M}\sum_{m=0}^{M}x^2(n-m)=\hat{P}_x(n-1)+\frac{x^2(n)-x^2(n-M)}{M} \tag{5}$$

The weight vector iteration equation of the normalized FLMS algorithm is

$$W(n+1)=W(n)-\frac{2\mu_0}{X^T(n)X(n)}e(n)r(n) \tag{6}$$

4. Control channel model

This paper models for the magnetic suspension floating raft active vibration isolation system using the method of off-line identification. After encourage the system by inputting the random signal, the acceleration signals above the vibration isolators are collected to identify the system. The incentive signal as input signal and the acceleration signal as output signal, the system is identified by the least square method. The identification is realized by the systemic identification toolbox of matlab. The identification model is selected after considering accuracy, reliability and transient response of the identification model. The transfer function of the identified control channel is:

Den11= {1 -9.52 38.8 -85.9 101 -39.3 -48.1 49.6 24.8 -47.7 -11.7 47.1 -6.33 -43.6 47.1 -23.4 6.00 -0.64}

Num11= {-0.29 2.84 -11.9 27.6 -35.0 15.9 17.5 -25.6 -2.20 25.6 -12.6 -17.1 29.1 -20.2 7.91 -1.69 0.157 0}

Den22= {1 -9.68 42.4 -110 189 -224 185 -105 39.5 -8.82 0.89}

Num22= {-0.0914 0.814 -3.23 7.53-11.3 11.3 -7.64 3.31 -0.84 0.0957 0}

Den33= {1 -9.50 38.6 -85.1 100 -37.1 -49.0 48.4 26.4 -47.5 -13.4 47.8 -5.06 -45.6 48.5 -23.9 6.11 -0.655}

Num33= {-0.255 2.46 -10.2 23.2 -28.8 12.4 14.8 -20.2 -2.57 20.3 -9.02 -13.7 21.8 -14.6 5.47 -1.12 0.0990 0}

Den44= {1 -10.1 44.8 -111 159 -109 -23.7 98.5 -30.4 -70.0 61.6 29.0 -83.9 67.5 -28.9 6.70 -0.669}

Num44= {-0.335 3.50 -16.2 42.6 -67.4 56.8 -2.13 -49.4 43.510.1 -52.9 53.5-29.9 10.1 -1.96 0.167 0}

The system is identified by using 50 times iteration of the least square method. The results show that the parameter estimation comes to stability, which is up to requests of the criterion function. (No.1 magnetic suspension vibration isolator corresponds to No.1 acceleration sensor) The accuracy of B11 is 93.75%, B22 89.02%, B33 95.48% and B44 92.68%. After comparison between the identification model and experimental model in accuracy, stability and transient response, recognition model meet the control requirements.

5. Simulation and Experiment

In order to test the convergence and isolation effect of the FLMS, the ordinary fixed step-size FLMS algorithm and the improved variable step-size normalized algorithm are applied to the feed-forward control system based on adaptive FIR filter to simulate and compare, in which the reference signal X=1.5*sin(2*50* π *t/2048)， the interference signal d=0.6*sin(2*50* π *t/2048), step width of the error signal e(k) and the weight coefficient W (k) u = 0.02, the reference signal frequency is 50Hz and the interference signal frequency is 50Hz. The control principle diagram of the normalized FLMS for the magnetic suspension floating raft active vibration isolation is shown in Figure 3.

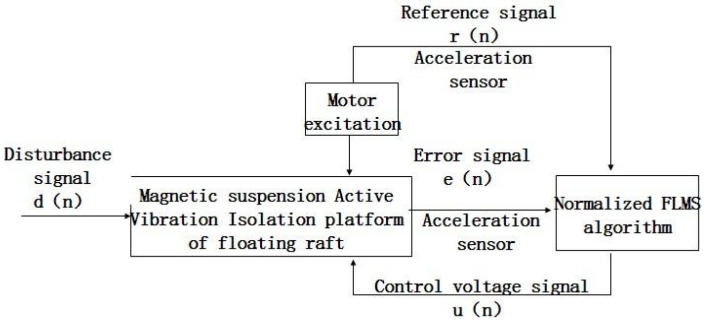


Fig. 3 The magnetic levitation floating raft of active vibration isolation to normalized FLMS control principle diagram

In this paper, the simulation for the weight vector iterative feed-forward control methods which are formed by two kinds of convergence coefficient is conducted. Then the comparison between the isolation effect and the convergence rate is preceded. Fig.4 is the comparison between the convergence rates, in which the solid line is the convergence rate curve of the normalized FLMS algorithm and the dotted line is the convergence curve of the ordinary FLMS algorithm. Compared to the ordinary, the normalized FLMS algorithm has faster convergence rate. Fig.5 is the spectrum comparison between the ordinary and the normalized FLMS algorithms, in which the ordinary and the normalized FLMS algorithms all have better effect near the frequency range of passive control signals(50.01Hz), and the isolation effect of the normalized FLMS is better.

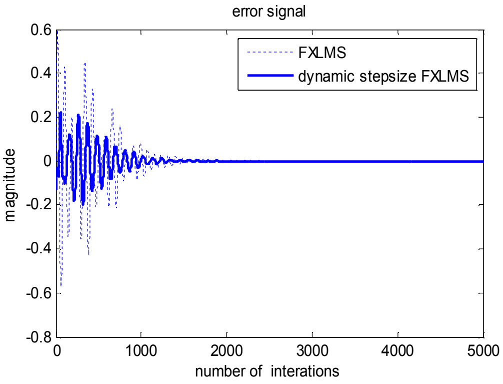


Fig. 4 The convergence speed comparison chart of FLMS and normalized FLMS algorithm

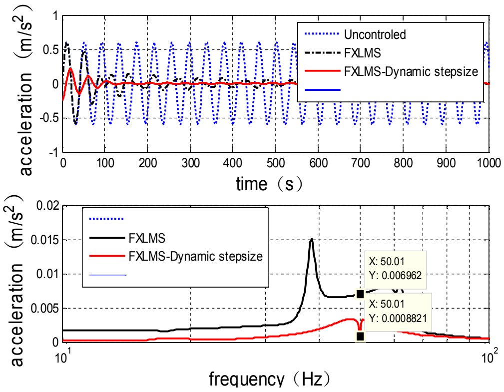
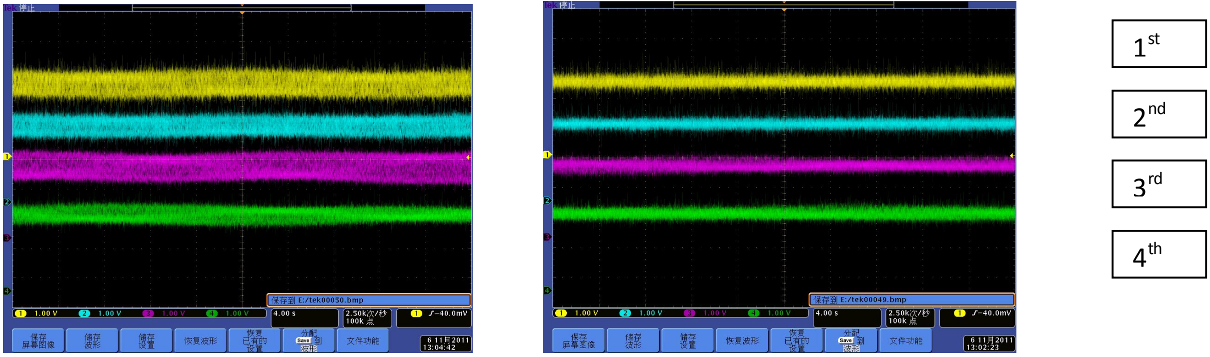


Fig.5 The spectrum comparison chart of FLMS and normalized FLMS algorithm

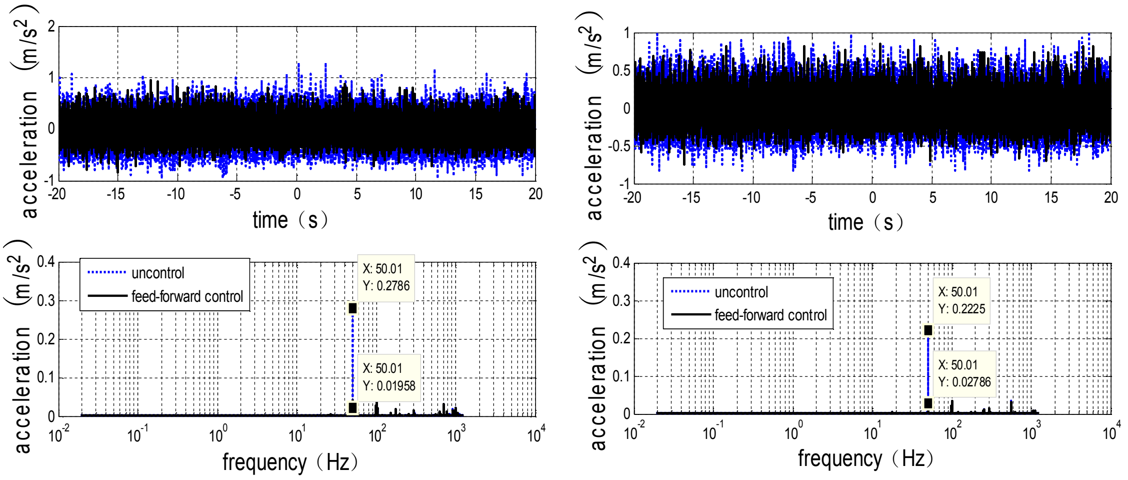
The normalized FLMS algorithm can be applied to the active control system of magnetic suspension floating raft, in which the reference signal (speed 3000r/min, frequency 50.01Hz, quality 144kg) comes from the induction motor, the amplification gain of the reference signal from charge amplifier is 1V/ms-2, amplification gain of the interference signal is 1 V/ms-2. The first starting step of the control algorithm is mu=0.0001. Fig.6 is the interfering signals of before and after controlling, in which 1,2,3,4 show 1st, 2nd, 3rd, 4th acceleration signals of the floating raft near the magnetic suspension active vibration isolator. Compared to the passive, the vibration signal of active vibration isolation system under control of the normalized FLMS algorithm reduced.



(A)Uncontrolled interference signals figure (B) Feed-forward control interference signal figure

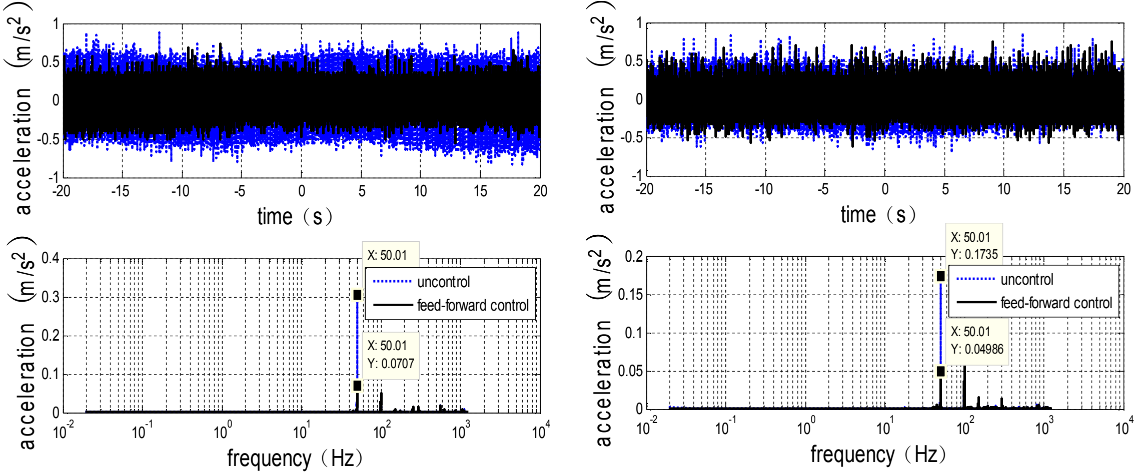
Fig.6 The acceleration signals of feed-forward control before and after the active vibration isolation system

In order to consider the reduction effect of acceleration accurately, spectrum analysis is conducted on the collected signals. Fig.8 shows the spectrum analysis for the acceleration signals of the active vibration isolation system before and after feed-forward control, in which the main component of reference signal is 50.01Hz, table 1 shows the acceleration in fig.8 before and after feed-forward control.



(A) 1st acceleration sensor signal spectrum analysis diagram

(B) 2nd acceleration sensor signal spectrum analysis diagram



(C) 3rd acceleration sensor signal spectrum analysis diagram

(D) 4th acceleration sensor signal spectrum analysis diagram

Fig.7 Feed-forward control before and after the active vibration isolation system acceleration signal spectrum analysis diagram

Table 1 Acceleration signal of the feed-forward control before and after the active vibration isolation system

Model	Passive acceleration values （m/s^{-2}）	Active acceleration values （m/s-2）	Decline in the percentage of
B11	0.2786	0.01958	93%
B22	0.2225	0.02786	88%
B33	0.3035	0.0707	97%
B44	0.1735	0.04986	72%

6. Conclusion

In this paper, the object is the active vibration isolation system of magnetic levitation floating raft. In order to solve the problems of feed-forward control method, the convergence rate of ordinary FLMS algorithm is slow, poor robustness, mutative convergence coefficient was applied to set weight vector iteration of normalized FLMS algorithm. Compared with the ordinary FLMS algorithm, the normalized FLMS algorithm has greatly improved the isolation effect and the convergence speed. The normalized FLMS algorithm is applied with active control system of the magnetic suspension floating raft vibration isolation, which has an overall improvement in 5-10dB and better effect in low frequency isolation, especially in the vicinity of the resonant vibration isolation effect is more obvious decrease 15dB - 25dB. It has proved the validity of the normalized FLMS algorithm in active vibration isolation system of magnetic levitation floating raft.

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References

[1] Guoqing Shang, Wei Li. Features of evolution on the ship floating raft system[J], Ship Science and Technology, 1999, 19(1):21-23.
[2] B. Widrow and S.D. Stearns, “Adaptive Signalprocessing,” Prentice Hall, New Jersey 1985.
[3] Tabatabaei Ardekani, W.H.Abdulla. Theoretical convergence analysis of FxLMS algorithm[J], Signal Processing, 2010, 90 (3):3046–3055.
[4] Yoichi Hinamoto, Hideaki Sakai. A Filtered-X LMS Algorithm for Sinusoidal Reference Signals—Effects of Frequency Mismatch[J], IEEE SIGNAL PROCESSING LETTERS, APRIL 2007, 4(14): 259-262.
[5] P.Babu1, A.Krishnan. Modified FxAFA Algorithm Using Dynamic Step Size for Active Noise Control Systems[J], International Journal of Recent Trends in Engineering, November 2009, 7(2):37-41.