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STUDY THE ACTIVE VIBRATION CONTROL SYSTEM OF THE PARALLEL 6-DOF PLATFORM*

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Abstract

With the development of high-energy synchrotron radiation light source with high energy, high brightness, low emittance and nano-scale light spot, accelerators and beamline stations have higher requirements for the stability of the system, and active vibration isolation technology has been paid more and more attention. It has become the key technology for the development of major scientific devices (such as high-energy synchrotron radiation light source, free electron laser, etc.) in the future. In this paper, an active vibration control system driven by piezoelectric ceramic actuator with strong adaptability is designed. NI Compact-RIO real-time control system and Fx-LMS adaptive filter control algorithm are used for the active vibration control system. The identification method of input and output channels and the active control module are simulated by MATLAB. And an active vibration control system based on a parallel 6-DOF platform was built for experimental verification. The experimental results show that the designed active vibration control system has a good control effect for low-frequency micro-vibration.

INTRODUCTION

The micro-vibration of synchrotron radiation light sources such as ESRF, APS and SSRF etc. shows that the low-frequency micro-vibration below 20Hz contributes significantly to the overall vibration in the frequency domain, which will cause micro-displacement and micro-deformation between pose-sensitive equipment and various parts of the optical system, thus affecting the performance of various precision components. Therefore, the control of low-frequency micro-vibration interference has become one of the factors that cannot be ignored in the development of advanced light source technology [1]. Low-frequency micro-vibration has the characteristics of miniature, inherent and difficult to control, which makes the micro-vibration dynamic environment become extremely complex and special, and the analysis and vibration control are very difficult, so it is urgent to restrain and control the micro-vibration [2]. Active vibration control has the advantages of good low frequency damping performance, high reliability, easy expansion and easy to realize multi-machine distributed parallel processing due to the existence of actuators [3]. It has been more and more widely used in large scientific devices such as synchrotron radiation light source, aerospace, industrial control, communication and scientific research.

THE ACTIVE CONTROL PRINCIPLE OF MICRO-VIBRATION

In the actual control engineering, the mathematical models of the actual controlled systems are difficult to be identified in advance through mechanism modeling or off-line system identification, or some parameters or structures of their mathematical models are in change. In the face of the situation that the characteristics of these systems are unknown or often changing and can't be completely determined in advance, how to design a satisfactory control system that can actively adapt to the unknown or changing characteristics is the problem to be solved by the adaptive control algorithm.

Principles of the FX-LMS Active Control

In practical application, the error signal (vibration response signal) e(n) is not a simple superposition of the filter output y(n) and the desired signal d(n). There is a transfer function of a secondary channel between y(n) and e(n). ***S***(z) is the transfer function from the control input of the actuator to the load response, which represents the dynamic characteristic of the actuator, as shown in Fig. 1. Morgan proposed Fx-LMS algorithm to eliminate the influence of secondary channel [4]. The identification process of secondary channels can be carried out by online or offline. The implementation of online identification is relatively complex, so the ***S***(z) is usually identified by offline [5]. According to the derivation process of the standard LMS algorithm, a similar result can be obtained,The whole filtered Fx-LMS algorithm can be simply summarized as follows:

$$\begin{cases} y(n)=\sum_{l=0}^{L-1} w_l x(n-l) \\ e(n)=d(n)-S^T Y(n) \\ w(n+1)=w(n)+\dfrac{\tilde{\mu} e(n) X'(n)}{\gamma + X'^T(n) X'(n)} \\ X'(n)=\left[x'(n) \quad x'(n-1) \quad \cdots \quad x'(n-L+1)\right] \\ x'(n)=\sum_{h=0}^{H-1} s_h x(n-h) \end{cases} \tag{1}$$

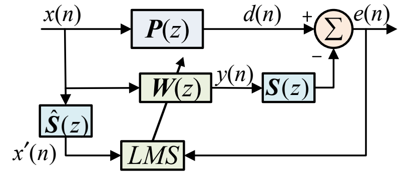

Figure 1: The principle of FX-LMS algorithm.

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Simulation of the Secondary Channel Identification Algorithm

In order to simulate and verify the system identification algorithm, it is necessary to assume the channel model to be identified. This paper assumes that the channel model to be identified is $\boldsymbol{S}(z)$ = [0.038,0.0875, -0.175, 0.035, -0.175, 0.0875, 0.21, 0.0385, 0.084, -0.105]. The excitation signal x(n) is taken as the order of Gaussian white noise. The order of $w(z)$ is set as order 14, the convergence factor Mu=0.1. The number of identification times are 2000. Through simulation, the secondary channel model parameters of the system can be effectively identified by using Fx-LMS adaptive algorithm,which was shown in Fig. 2.

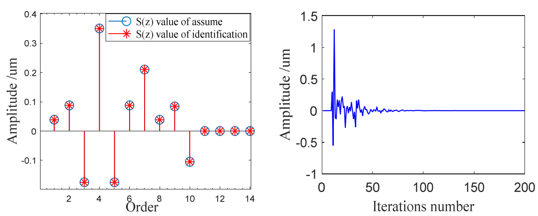

Figure 2: The secondary channel identification results(left) and the error of the simulation(right).

Simulation of Active Vibration Control Algorithm

In this paper, the MATLAB is used to simulate and verify the algorithm of the active vibration control module. The excitation source set here is a square sinusoidal wave with amplitude of 2mm at 5Hz, 15Hz and 20Hz, and the multi-frequency interference signal with white Gaussian noise of 0.1um is superimposed. The order of the weight $w(z)$ is 16, and the convergence factor mu=0.005. The results in the above identification algorithm test is shown in Fig. 3. By calculation, the vibration amplitude of the system is reduced from 4.96um to 0.15um. The system has a good isolation effect in theory.

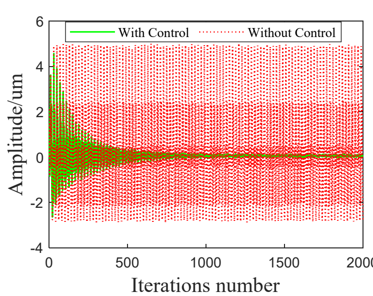

Figure 3: Simulation of active vibration control.

DESIGN OF ACTIVE VIBRATION CONTROL SYSTEM

The control process of the active vibration control system designed in this paper mainly includes two parts: the secondary channel identification process and the active vibration control process. The process of estimating the transfer function of the secondary channel is called the secondary channel modeling process. In practical application, firstly, the external interference source of the system should be turned off, and the FPGA controller generates the Gaussian white noise voltage signal and outputs it to the piezoelectric ceramic controller, which is used as the excitation source signal of the secondary channel modeling. Then turn to the active control process, and realizes the adaptive active vibration control function through the vibration signal acquisition and the iterative calculation control of the active control algorithm. The whole control process is shown in Fig. 4.

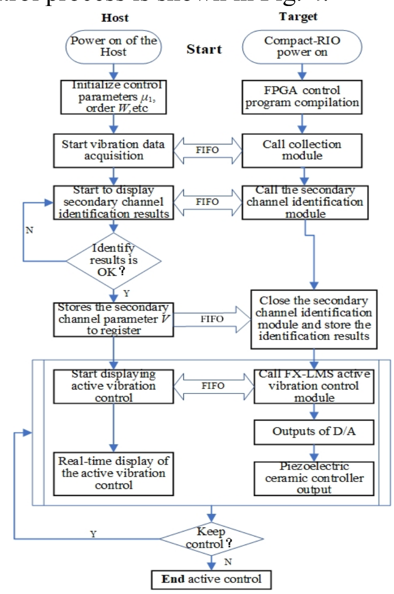

Figure 4: Flow block of the active control system.

The software architecture of the active vibration control system is shown in Fig. 5. The system software is mainly composed of the host RT software and the target FPGA software. The host computer software is mainly composed of vibration data display interface, secondary channel identification interface and active vibration control interface. The target computer software is mainly composed of vibration data acquisition module, secondary channel identification algorithm module, Fx-LMS active vibration control algorithm module and 6-channel piezoelectric ceramic drive control module, which mainly realizes the functions of vibration data acquisition and transmission, closed-loop control signal output control and active vibration control during the operation of the system.

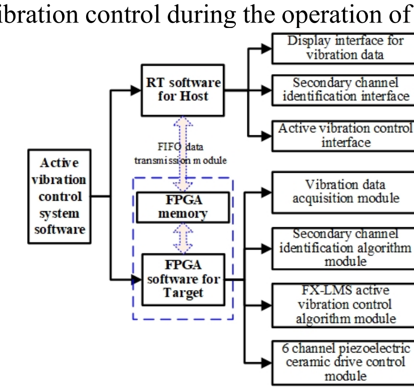

Figure 5: Software architecture of the active vibration control system.

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EXPERIMENTAL STUDY ON ACTIVE VIBRATION CONTROL

This paper presents a single direction active vibration control system based on a parallel 6-DOF platform is shown in Fig. 6. It is mainly used to control the low frequency micro-vibration in the vertical Z direction of the platform [6]. The vibration acquisition module in the control system collects the vibration signal in the Z direction of the upper and lower plane of the parallel platform in real time. The signals are amplified and adjusted by Compact-RIO charge, and then the system excitation signals and the platform response signals are transmitted to the FPGA processor in real time. The Fx-LMS module in FPGA analyzes and processes the control target signal, obtains the real-time feedback control quantity, and sends out the control signal through the output module. The piezoelectric ceramic actuator driven by the piezoelectric controller produces a reaction force acting on the plane of the parallel platform to achieve the effect of vibration reduction.

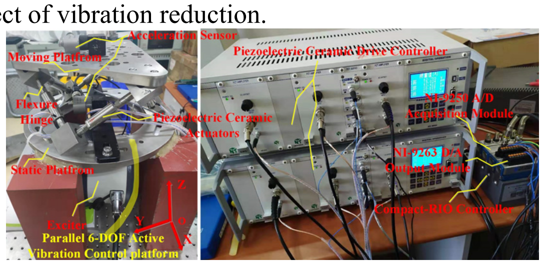

Figure 6: Photograph of the active vibration control system.

In the secondary channel Parameter identification experiment,the identification results of the Z direction of the platform is shown in left Fig. 7, which shows that the channel parameters of the system are mainly concentrated in the first 80 orders. At the same time, five groups of white noise signals of different sizes are used to drive piezoelectric ceramic actuators, and the standard deviation distribution of secondary channel parameters is shown in right Fig. 7. The maximum standard deviation of secondary channel parameters is 0.175. Different sizes of white noise signals have little influence on the identification of the secondary channel parameters.

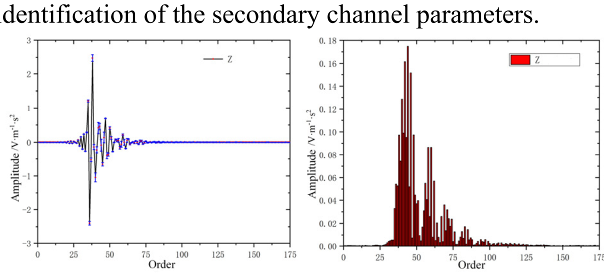

Figure 7: Secondary channel identification result of active vibration control system (left), and Standard deviation distribution of secondary channel parameters (right).

In the active vibration control experiment, different frequency excitation and vibration control experiments on the Z direction of the platform are carried out to test the low frequency damping effect of the control system. The vibration damping effect under different excitation frequencies are listed in Table 1.

Table 1: Vibration Reduction Results under Different Frequency Exciting Conditions

exciting frequency /Hz	with control /µm	without control /µm	vibration reduction rate /%	vibration attenuation /dB
7	9.179	2.247	75.52	14.66
10	9.475	1.017	89.27	23.89
15	9.955	0.512	94.85	52.04
20	9.634	0.554	94.24	43.41
25	7.234	0.412	94.31	70.21
30	6.165	0.561	90.91	58.16
40	4.924	0.943	80.84	64.23
50	4.493	0.834	81.43	71.82

Figure 8 shows the experimental results of active vibration reduction, it can be seen that under the action of sinusoidal interference signal of vibration exciter at 7Hz, the amplitude of displacement vibration is reduced from 9.179µm to 2.247µm, which is reduced by 75.52%, the vibration amplitude of the platform attenuates to 14.665dB. With the increase of the excitation frequency, the active damping efficiency and attenuation of the active damping control system increase obviously, and the vibration damping effect is better.

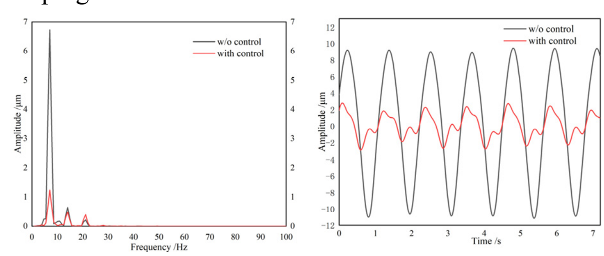

Figure 8: Experimental results of active vibration control.

CONCLUSION

In this paper, an active vibration control system is designed on a parallel 6-DOF platform driven by a piezoelectric actuator. The Fx-LMS adaptive control algorithm is used as the system control method. The medium and low frequency excitation test of 7Hz to 50Hz was carried out on the platform, and the low-frequency micro-vibration control in vertical Z direction was realized, especially the upper platform achieved a good vibration reduction effect of 75.52% in the vertical Z direction under the low frequency excitation interference of 7 Hz which verifies that the active vibration control system designed in this paper is feasible. The system can lay a foundation for low-frequency micro-vibration control system and multi-directional adaptive active control of southern advanced synchrotron radiation light source precision equipment in the future.

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REFERENCES

[1] P. Kristiansen *et al*., "Vibration measurements of high heat-load monochromators for DESY PETRA III extension," *J. Synchrotron Radiat.*, vol. 22, pp. 879-885, 2015. doi: 10.1107/S1600577515005664

[2] C. Doose, S. Sharma, "Investigation of Passive Vibration Damping Methods for the Advanced Photon Source Storage Ring Girders," in *Proc. MEDSI'02*, Chicago, IL, USA, 2002, pp 133-139.

[3] R. L. Breton, G. Deleglise, J. Allibe *et al*., "Nanometer Scale Active Ground Motion Isolator," *Sens. Actuators, A*, vol. 204, pp. 97-106, 2013. doi: 10.1016/j.sna.2013.09.020

[4] D.R. Morgan, C. Sanford, "A control theory approach to the stability and transient analysis of the filtered- xLMS adaptive notch filter", *IEEE Transactions on Signal Processing*, vol. 40, no. 9, pp. 2341-346, 1992. doi: 10.1109/78.157237

[5] Yixin Chen and J. E. McInroy, "Decoupled control of flexure-jointed hexapods using estimated joint-space mass-inertia matrix," *IEEE Transactions on Control Systems Technology*, vol. 12, no. 3, pp. 413-421, May 2004, doi: 10.1109/TCST.2004.824339

[6] Liu Ren-hong *et al.*, "Study of Micro-vibration Active Control System Base on Piezoelectric Driver," *Atomic Energy Science and Technology*, vol. 54, no. 10, pp. 1940-1946, 2020. doi: 10.7538/yzk.2019.youxian.0757