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Research of Air-Magnet Active Vibration Isolation System Based on H∞ Control

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Abstract. Considering the uncertainty of air-magnet active vibration isolation system (AMAVIS), passive vibration isolation was combined with active vibration isolation, which adopted H∞ control strategies. System identification method was used to get the channel model. By adopting mixed sensitivity design strategy, weighting functions were chosen and H∞ controller was designed. Both simulation results and experimental results show AMAVIS based on H∞ control had satisfying effect of vibration reduction in assigned frequency band.

1 Introduction

Air spring[1, 2] vibration isolator has large bearing capacity, small size, low frequency and high frequency vibration isolation performance is good, the load can be adjusted, highly controllable[3]. It is an ideal kind of passive vibration isolator, whereas maglev vibration isolator whose stiffness and damping can be adjusted and controlled, wide spectrum, quick response, flexible control, is an ideal kind of active vibration isolator. Both will be able to make full use of the advantages of maglev vibration isolation and air spring vibration isolation through AMAVIS which can improve the isolation performance of AMAVIS in the whole frequency band[4].

In the active control system of structural vibration, due to influence of residual modes, parameter perturbation and errors of sensing system and actuation system model, it is difficult to establish an accurate model. But the robust H∞ control algorithms, especially the H∞ control [5~9] can be a good deal of the robust performance and stability robustness of the systems. This experiment used the output acceleration sensor as the feedback signal and exciter as the control actuator, used experimental identification to get the model and designed the controller by robust H∞ control theory, finally established a air-magnet active vibration isolation control system.

2 H∞ mixed sensitivity problem

AMAVIS applies mixed sensitivity method to design control. H∞ robust mixed sensitivity design method is based on the establishment of the basic system of minimum sensitivity design problem and robust stability problem. The sensitivity of the system, refers to the system output sensitivity to external disturbance, reflects the system in aspects of the impact of the steady-state accuracy of the closed-loop system to reject the external disturbances; and robust stability refers to the robustness of system stability, that is, when there are model perturbation, the system can still maintain stable. Sensitivity and robust stability is a pair of contradictory existence, so the mixed sensitivity design method is used to compromise in practical application.

As is shown in Fig.1, $W_1(s)$ is the sensitivity weighting function, $W_2(s)$ is the control sensitivity weighting function, $W_3(s)$ is the complementary sensitivity weighting function, $r(t)$ is a disturbance input, $e(t)$ is the tracking error, $y(t)$ is the system input, and the $P(s)$ is the controller to be designed, $G(s)$ is the channel transfer function of a closed loop control system.

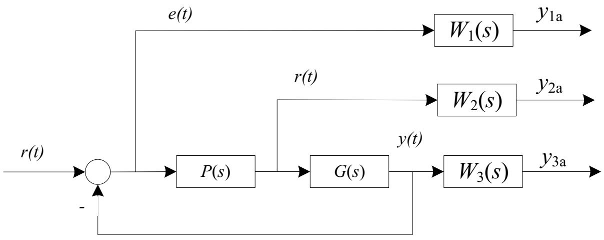

Fig. 1 Mixed sensitivity problem

The generalized object for mixed sensitivity problem is:

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$$P(s)=\begin{bmatrix} W_1 & -W_1G \\ 0 & W_2 \\ 0 & W_3G \\ I & -G \end{bmatrix} \tag{1}$$

H∞ robust mixed sensitivity problem is to solve a controller such that

$$\left\| \begin{matrix} W_1S \\ W_2R \\ W_3T \end{matrix} \right\| < 1 \tag{2}$$

S is the sensitivity function of system, R is the sensitivity function of controller, and T is the complementary sensitivity function. After determining the control channel model $C(s)$ and selecting $W_1(s)$, $W_2(s)$, $W_3(s)$, controller $P(s)$ can be solved by MATLAB.

3 H∞ control simulation and experiment

3.1 Control device

The experimental apparatus is shown in Fig.2. The disturbance acceleration signal of electromotor vibration amplifies the signal through conditioning amplifier, and then passes the low-pass filter, leaving the 0-200Hz signal into the controller, the output of the controller acts on the exciter amplifier, excitation on the cover is to counteract the vibration, vibration acceleration sensors on the system response to external disturbance force.

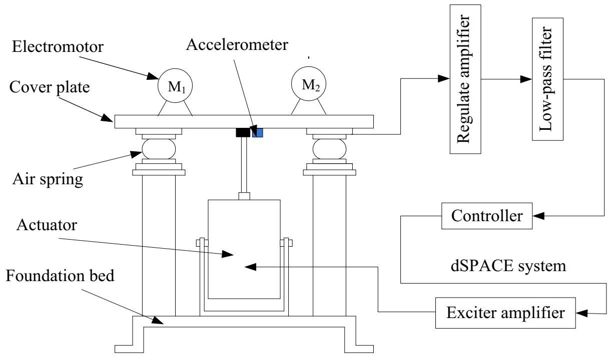

Fig. 2 Air-magnet active vibration isolation experiment system

3.2 Experimental modeling of control channel

AMAVIS is a complex system which is strong coupling and nonlinear. Physical modeling has great limitations; however, identification method can provide an effective means by which the mathematical description of the system through external response characteristics can be obtained. By using least square method to do system identification, the frequency domain identification model of the experiment system is shown in Fig. 3.

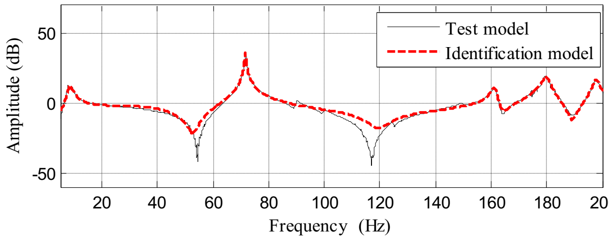

Fig. 3 Experimental frequency characteristics of Bode diagram

3.3 Single frequency control

$W_1(s)$ is usually selected according to the amplitude-frequency characteristics of external disturbance. Considering that 20Hz sinusoidal signal is used as the disturbance force frequency in the single frequency control, so two order system is used as $W_1(s)$, $W_1(s)$ pole is located in 20Hz, namely $W_1(s)$ is at the maximum when at 20Hz, as the control key. For $W_2(s)$, in order to reduce design conservatism, it should meet the true shape of the control channel model uncertainty $\triangle(s)$ as much as possible, but the use of black box modeling in this paper is difficult to determine the shape of the $\triangle(s)$, in order not to increase the order number of controller, generally, $W_2(s)$ is a constant. After a series of simulation and debugging by MATLAB, weighting functions are:

$$W_1(s)=\frac{s}{s^2+0.3142s+2.467\times10^4} \tag{3}$$

$$W_2(s)=W_3(s)=0.5 \tag{4}$$

Input frequency 20Hz for sinusoidal acceleration interference signal, for opening and closing the output acceleration sensor are respectively sampled and mapped, as shown in Fig.4 is the control before and after interference signal time domain chart. The simulation clearly shows that the sinusoidal disturbance input signal by 20Hz active control after stability attenuation decreases by 90%, it has a good damping effect and the controller design is correct and reasonable.

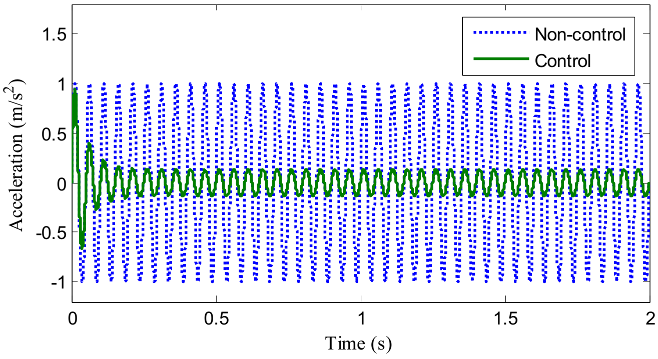

Fig. 4 Control before and after the interference signal time domain graph

In active vibration isolation test-bed based on air-magnet hybrid structures, a motor runs while another motor not. After adjusting inverter motor to stable running speed of 1200 r/min, the cover plate interference signal energy was found mainly concentrated in the vicinity of 20Hz frequency and 71.4Hz, the peak 20Hz response was caused by the motor frequency, combined with the finite element analysis results, 71.41Hz peak was corresponding to the first order bending flexible modes of the cover. The active control was opened to acquire the real-time acceleration signal of the cover plate centre.

Fig.5 shows that the amplitude of 20Hz signal decreases by about 80% under control of single frequency interference, but the amplitude of 71.4Hz signal increases slightly. Because the 71.4Hz signal has more energy than 20 Hz frequency energy, the acceleration signal on the whole almost has no attenuation, vibration almost has no decrease. Therefore, the controller design must consider the effect of 71.4Hz response.

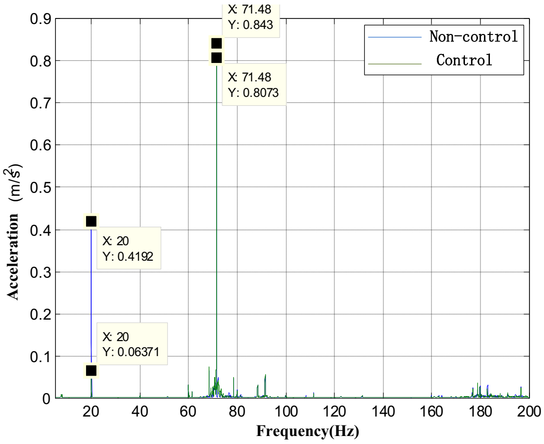

Fig. 5 Single motor (speed 1200 r/min) single frequency control spectrum

After the new design of dual frequency interference controller in single motor excitation to restrain 20Hz and 71.4Hz signal amplitude at two frequencies, another experiment was carried, the results are shown in Fig.6. The figure shows the signal amplitude decreases above 50% after control.

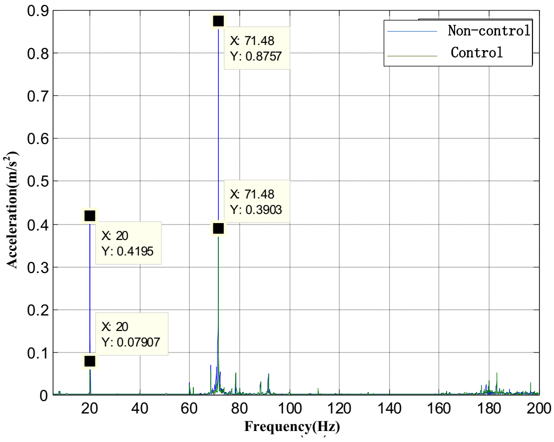

Fig. 6 Single motor (speed 1200 r/min) double frequency control spectrum

3.4 Narrow band control

Because the motor may not be stable during operation, the speed fluctuation will cause changes in the frequency of the interference signal. In addition, when there are multiple excitation sources, the error signal will be produced by the superposition of multiple frequency sinusoidal signals. Therefore, according to the frequency range of interference, this paper designed a 23Hz ~ 27Hz narrow band interference controller to control system.

During simulation, disturbance signal by sine acceleration signal superposition of 23Hz, 25Hz, and 27Hz was input, for opening and closing the controller, the output acceleration sensors were respectively sampled.

As is shown in Fig.7, narrow band control system has obvious inhibitory effect on the superimposed interference signals, the interference signal amplitude decreases by about 50% when the system is stable, reaches narrow band control requirements.

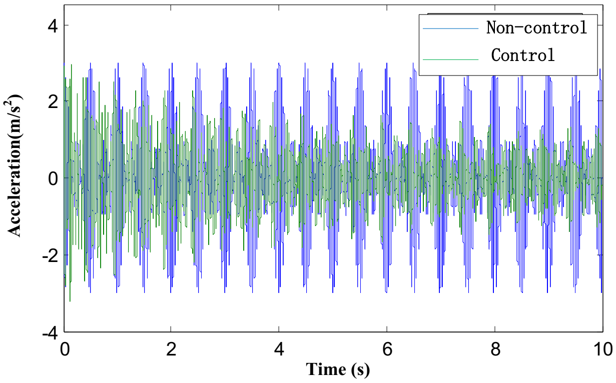

Fig. 7 Control before and after interference signal time domain waveform graph

In order to verify the narrow band control system's sensitivity and control effect on the frequency of the interference signal, experiments were carried out. The rotation speed of the motor increased from 1380 r/min to 1620 r/min sequentially, every increase was 60r/min, equivalent to the interference signal frequency range 23Hz ~ 27Hz.

Fig.8 is for narrow band interference suppression effect comparison, it can be seen that the experiment's and simulation's draw chart are consistent, the requirement of the experiment is that the effect of error signal attenuation reaches more than 50%, that is to say, line should be below the line whose longitudinal coordinate is 0.5, and either experiment or simulation basically meets the requirement.

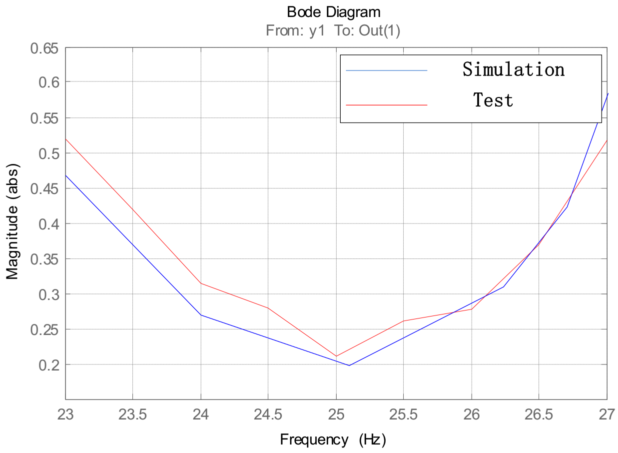

Fig. 8 Inhibitory contrast effect of narrow band interference

4 Conclusions

This paper was based on the theory of H∞ control, the output acceleration sensor was used as the feedback signal and exciter was adopted as the control actuator, then a set of AMAVIS based on the dSPACE real-time simulation system was established. Experiments showed that this method could obtain satisfying effect of vibration reduction in assigned frequency band.

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