International Journal of Civil Engineering and Environmental Science. Volume 3, Issue 1, (2015) 18-22
http://www.cayley-nielson.com/ijcees/

Active Vibration Isolation System Based on Piezoelectric Smart Materials

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Abstract

Active vibration control based on the piezoelectric smart structure is an important new issue in the design and control of structural dynamic research field. This paper uses the piezoelectric ceramic piezoelectric properties to achieve active vibration control of the piezoelectric structure, and establish the model of the active vibration isolation system. Use MATLAB language to determine the parameters of the controller, analyze the impact of various parameters on the controlled object. Through computer simulation, contrast the effect of vibration isolation before and after control. The results show that the active vibration isolation system has good low-frequency signal isolation effect.

Keywords: smart materials; Piezoelectric ceramic; Active Vibration Isolation System; MATLAB.

1. Introduction

The vibration of the mechanical structure may affect the accuracy and stability of the machine instrumentation, the severe vibration, especially the low-frequency vibration, may cause the parts fatigue damage or the resonance, which shorten the life of the structure and damage the structural element. Active vibration control technology with the potential superiority of better control effect and adaptability has become the research hotspot.

The emergence of smart materials piezoelectric ceramics has opened up a new avenue for the active control of the structural vibration inhibition. Structural vibration active control based on the piezoelectric ceramic elements has simple constitution, low cost, light weight , small size, unique power properties, fast response, low power consumption and no transmission mechanism, which makes it easy to install and conducive to the overall design arrangements[1]. Therefore, it has a broad application prospects.

2. Piezoelectric ceramic actuator

To use piezoelectric ceramic as actuators of active vibration isolation system, the basic principle is: the inverse piezoelectric effect--when an electric field is applied, material produce a controllable strain in an instant. In order to obtain a larger displacement and the amount of force output, in accordance with the electrical parallel connection and mechanical series connection, make n identical piezoelectric sheets bonded together to form a piezoelectric stack[2,3]. Ignore the energy loss between each of the piezoelectric sheet, the relational expression of the output displacement δ and the input voltage U is[4]:

$$\delta = \frac{F}{K} + nd_{33}U \tag{1}$$

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March, 2015

Where, F is the piezoelectric axial load, K is piezostack equivalent static mechanical stiffness, $K = \frac{c_{33}^{E} A}{nt}$, t is the axial length of the monolithic piezoelectric body, c_{33}^{E} is a modulus of elasticity of the piezoelectric ceramic, A is the piezoelectric sheet cross-sectional area, d_{33} is the piezoelectric constant.

3. Active vibration isolation system modeling

3.1 The basic control principle of active vibration isolation system and controller design

The controller is the core area of active control system, divided into feed forward controller and feedback controller. The feed forward controller is suitable for the occasion to take a particular disturbance compensation measures. Feedback controller is able to reduce or eliminate the impact of the disturbance on the output when disturbance factors are more and undetectable, and suitable for complex systems and parameter uncertainty system. Taking into account the uncertainty of the interference, this paper uses a feedback controller to control the controlled object. Active vibration isolation system control principle is shown in Fig.1. It shows the input U(s) and $X_2(s)$ the transfer function between output as follows:

$$\frac{X_2(s)}{U(s)} = \frac{G(s)}{1 + G(s)E(s)} \tag{2}$$

Where, G(s) is a controlled object, E(s) of the feedback controller.

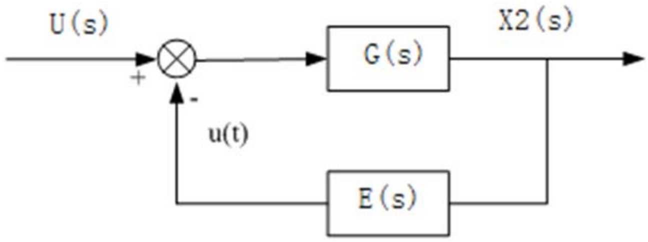

Fig.1 Control schematics of active vibration isolation system

Seen from the formula (2), to make the output $X_{2(}s)$ becomes small, must let $\left|G(s)E(s)\right| >> 1$, at same time make sure the entire system is stable. In order to simplify the design of the controller, E(s) is taken as the linear superposition of the gain coefficient C_x, C_v.

3.2 Active vibration isolation system transfer function derivation

The design of the isolator system must have considerable attenuation effect with the interference signal of the full frequency band. The survey found that passive vibration isolation alone cannot solve low frequency disturbances' isolation. Known from the literature [5], to isolate low frequency vibration, active and passive combined double isolation program works best. When active vibration isolation device is placed between the middle platform and the load platform, the vibration isolation system is difficult to isolate ultra-low frequency vibration, but it has a good high-frequency vibration isolation performance; When active vibration isolation device is placed between the middle platform and the basic platform, the effect of the low-frequency vibration isolation is the best. The active vibration control studied in this paper is mainly used to low-frequency vibration isolator, so the piezoelectric actuator is installed between the middle quality and substrate.

Fig.2 is a schematic diagram of active vibration isolation system.

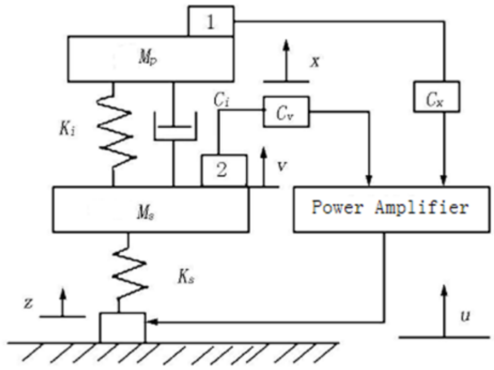

Fig.2 Active vibration isolation system diagram

As shown in Figure 2, u is the vibration displacement of the substrate, z is the output displacement of the piezoelectric actuator, v is the vibration displacement of the intermediate, x is the vibration displacement of the isolation object, C_x, C_v is the gain coefficient, 1,2 is the speed sensor.

The vibration equation is:

$$M_p\ddot{x} + C_i(\dot{x} - \dot{v}) + K_i(x - v) = F_p \tag{3}$$

$$M_s\ddot{v} + C_i(\dot{x} - \dot{v}) + K_i(x - v) + K_s(v - z) = 0 \tag{4}$$

$$z - u = -C_v v - C_x x \tag{5}$$

Where， M_p is load quality, K_i, C_i are respectively elastic and damping coefficients of the isolator element, M_s is the quality of the intermediate mass, F_p is the force exerted on the load, mainly gravity, K_s is the elastic coefficient of the piezoelectric ceramic.

Laplace transform of formula (3) to (5) obtain the active vibration isolation system transfer function is:

$$T(s) = \frac{K_S(K_i + C_{is})}{(M_s s^2 + K_s C_v + K_s)(M_p s^2 + K_i C_i s) + (K_i + C_i s)(M_p s^2 + K_S C_x s)} \tag{6}$$

4. Active vibration isolation system simulation

4.1 Determination of the controlled object parameters and controller parameters

In this study, the piezoelectric actuators are mechanical packaged piezoelectric ceramic Harbin XinMingTian Co. Ltd, Model: 20VS15, elastic coefficient Ks=4.38*10e8N/m. Piezoelectric actuator is the rigid actuator; the elastic coefficient is relatively large. Taking into account the vibration isolation system is easy to implement, let M_p=10kg, K_i=2*10e6N/m, C_i=1395N•s/m, λ=M_s/M_p. Take different values of λ, use MATLAB to obtain Bode diagram of the active vibration isolation system. Shown as Fig.3, with the decrease of the value λ, the isolation efficiency is almost constant at low frequencies, while at high frequencies increases. Consider that the interference signal is not completely deterministic, take λ=0.025, M_s=0.25kg.

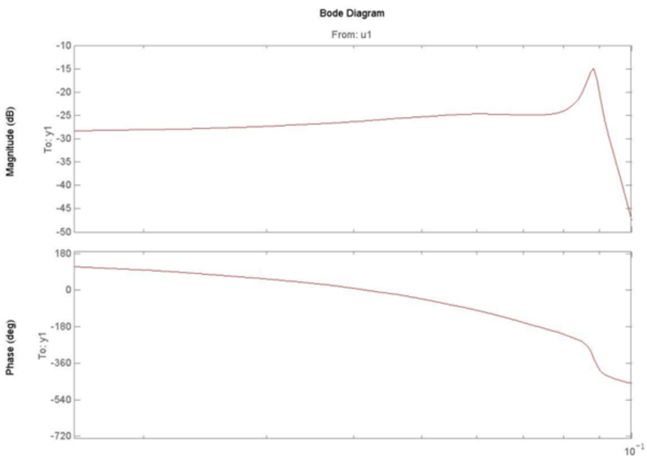

Fig.3 The change of the vibration System Bode diagram

The design of the controller must first ensure the system is stable, which called for the transfer function poles are strictly in the left half s-plane. Secondly, in order to improve the isolation efficiency of the system, it also requires the modulus of the transfer function is small. When the operational amplifier has high magnification, it is prone to blocking. Therefore, we should select the lowest gain coefficients which meet the conditions. Simulation results show that minimum gain coefficient that meet the conditions is C_x = 0. 2, C_v=0.4.

4.2 The simulation results

Before and after control, the change of the vibration transmissibility along with the frequency is shown in Fig.4 & Fig.5.

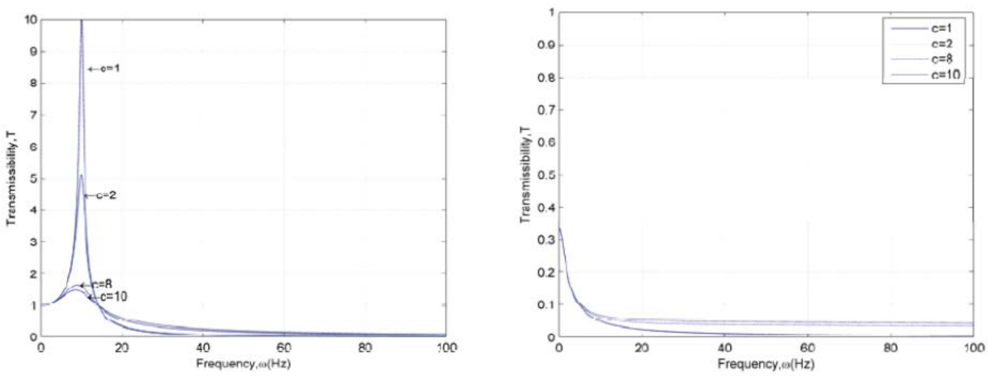

Fig.4 & Fig.5 The change of the vibration transmissibility

Where, c is critical damping coefficient.

We can see that in low frequency stage the compound control performances much better than the passive control. It indicates that combining active control with the passive control is necessary, and its effect is remarkable.

5. Conclusion

Presently, the harsh environment has become a big barrier to the practical implementation of many advanced equipment. Through the above simulation, the usage of smart structures in the vibration control technology can overcome the disadvantages of traditional active control such as the sensor, actuator, controller and controlled object are relatively independent distributed, extra load is big and so on, to achieve the ideal vibration control effect. Besides, the smart structures have achieved fruitful results in vibration control domain after decades of research. And With the development of signal processing, electronic technology, modern control theory and test technology, the active control method has a broad application prospects.

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