TSINGHUA SCIENCE AND TECHNOLOGY
ISSN 1007-0214 05/19 pp533-539
Volume 12, Number 5, October 2007

Improved Active Vibration Isolation Systems

SUN Hongling (孙红灵), ZHANG Kun (张 鲲),
CHEN Haibo (陈海波)**, ZHANG Peiqiang (张培强)

CAS Key Laboratory of Mechanical Behavior and Design of Materials, Department of Modern Mechanics, University of Science and Technology of China, Hefei 230026, China

Abstract: The control force, feedback gain, and actuator stroke of several active vibration isolation systems were analyzed based on a single-layer active vibration isolation system. The analysis shows that the feedback gain and actuator stroke cannot be selected independently and the active isolation system design must make a compromise between the feedback gain and actuator stroke. The performance of active isolation systems can be improved by the joint vibration reduction using an active vibration isolation system with an adaptive dynamic vibration absorber. The results show that the joint vibration reduction method can successfully avoid the compromise between the feedback gain and actuator stroke. The control force and the object vibration amplitude are also greatly reduced.

Key words: passive-active; vibration isolation; actuator stroke; dynamic vibration absorber

Introduction

The demand for higher performance vibration isolation systems has increased in many scientific and industrial fields such as semiconductor manufacturing and engine mounts for automobiles and ships. Passive vibration isolation systems cannot provide adequate isolation in many structures. Many kinds of active isolation systems have been developed[1-5]. Fuller et al.[1] compared three kinds of active isolation systems and found that for active control, the use of an actuator in parallel with a passive isolation stage is the most practical method to reduce the control force. Therefore, a practical active isolation system consists of three components in parallel: a spring providing static stiffness, an actuator providing an active force, and a damper. Xing et al.[5] developed modified active isolation systems in which the actuator is in series with a softer spring or a smaller damper which are then in parallel with a spring providing the static stiffness. The modified system overcomes the limitations on the feedback gain of conventional active isolation systems, but the actuator force is not reduced. Many active isolation systems can provide good isolation if their control forces are large enough. However, isolation systems with large control forces are not practical. Chopra[6] reviewed the state-of-the-art of smart actuators and sensors and integrated systems and pointed out that for applications of smart structure technology to aerospace and other systems, one of the major barriers is the actuator stroke. Most commercially available smart actuators (such as piezoceramics and magnetostrictors) are short stroke and low force devices. Therefore, both the control force and the actuator stroke in active isolation systems are important performance indices.

On the other hand, most research has focused on the isolation performance of the active isolation system rather than its influence on the amplitude of the object's movement. Sun et al.[7] analyzed a single-layer active vibration isolation system to show that the active

Received: 2007-03-15
** To whom correspondence should be addressed.
E-mail: hbchen@ustc.edu.cn; Tel: 86-551-3603724

vibration isolation may not adequately reduce the vibrations of an isolated object when the excitation frequency is less than a critical frequency. They then proposed a joint vibration reduction method combining an active vibration isolation system and a dynamic vibration absorber (DVA) to reduce the vibration amplitudes during low frequency response excitation. However, the use of a passive dynamic vibration absorber made their method effective only near its resonance frequency. In recent years, many adaptive vibration absorbers have been developed that can effectively suppress vibrations of the primary structure over a wide range of frequencies[8-13].

This paper discusses typical problems in typical active vibration isolation systems and compares the control force, feedback gain, and actuator stroke of several passive-active vibration isolation systems. A joint vibration reduction method that combines an active vibration isolation system and an adaptive dynamic vibration absorber are then discussed which improves the performance of the active isolation systems.

1 Typical Problems in Active Vibration Isolation Systems

For simplicity, the vibration of a single degree-of-freedom (SDOF) system is considered in the following analysis. This system represents the simplest possible model of a mounted machine whose vibrations need to be isolated from a receiving structure. As shown in Fig. 1, a typical passive-active vibration isolation system consists of a spring with stiffness coefficient K, a damper with viscous coefficient C, a lumped mass M, and an actuator providing an active force f_a directly to the receiver which reacts against the system mass. Here the excitation force f_s is applied to the system mass M with x as the displacement of the lumped mass. The system dynamics equation can be written as

$$M\ddot{x} + C\dot{x} + Kx = f_a + f_s \quad (1)$$

For the ideal vibration isolation system, the force transferred to the receiver is zero. This requires that the control force f_a be given by

$$f_a = C\dot{x} + Kx \quad (2)$$

Substituting Eq. (2) into Eq. (1) gives the very simple motion equation

$$M\ddot{x} = f_s \quad (3)$$

Taking into account a harmonic exciting force with frequency ω, let $f_s = A_{f_s} e^{j\omega t}$, $x = A_x e^{j\omega t}$, and $f_a = A_{f_a} e^{j\omega t}$, where A_{f_s}, A_x, and A_{f_a} are the complex amplitudes of the exciting force f_s, the displacement x, and the control force f_a. Substituting these into Eqs. (1)-(3) gives the relationship between the three amplitudes

$$A_x = -\frac{1}{M\omega^2} A_{f_s} \quad (4)$$

$$A_{f_a} = (K + j\omega C) A_x \quad (5)$$

For the system in Fig. 1, the actuator stroke A_{as} is equal to the modulus of the complex amplitude of the displacement x:

$$A_{as} = |A_x| \quad (6)$$

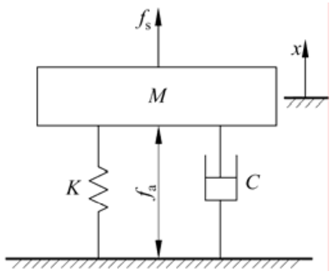

Fig. 1 Typical active vibration isolation system

The control force in Eq. (2) is a function of both the velocity and the displacement and the gain for the displacement feedback is the spring stiffness. For a large aircraft or machine, a sufficiently strong spring supports the mass. Therefore, the controller given in Eq. (2) requires a very large feedback gain. However, such large feedback gains may be unachievable in practical active feedback devices, so various methods have been proposed to reduce the feedback gain in active vibration isolation systems.

The vibration amplitude of isolated object is also an important isolation performance index because larger amplitudes will cause other problems, for example, with the alignment of shafts with other machines. Sun et al.[7] analyzed the influence of the active isolation system on the vibration amplitude. For the system in Fig. 1, if the actuator is removed, then the system becomes a passive isolation system whose dynamics equation is

$$M\ddot{x} + C\dot{x} + Kx = f_s \quad (7)$$

For a harmonic excitation force, the complex ampli-