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ACTIVE VIBRATION CONTROL OF HARD-DISK DRIVES USING PZT ACTUATED SUSPENSION SYSTEMS

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Abstract

In this paper, an active PZT-based suspension system is designed to block vibration from the ground disturbance into hard-disks when notebooks experience incident drop or impact. To build an active bridge for isolating vibration, the suspension structure of the hard-disk's case is redesigned such that the piezoelectric actuators can be attached and perform active controls. Due to the complicated structures of the notebook, experiments are performed to obtain the frequency response of the plant. Two resonances are found within the control bandwidth of 0 to 100 Hz. A quantitative Feedback Theory (QFT) controller is designed based on the frequency response function. It is shown that more than 20 dB reductions are achieved at the first and second modes. The settling time of the impact testing can be reduced by more than 90 percents. Moreover, the maximum peak of the impact testing is only about 50% of the uncontrolled case.

1. INTRODUCTION

The data stored in a hard-disk drive is sometimes much valuable than the hard-disk itself. Incident drop of notebooks might cause damages of hard-disks drive and deteriorate the stored information. Most of research on protecting hard-disks from incident drop can be categorized into two fields: active vibration control of head slider suspension system and passive protection of hard-disk by designing a highly-damped notebook's pedestal. The first approach attaches actuators on reading head-sliders which are located inside of hard-disk[1-2]. Another way of protecting hard-disks is to utilize free-fall sensors to detect abrupt acceleration signals. As the sensors receives abnormal signals, the controller of hard-disks commands reading heads to stop reading and move away from the disks to prevent the damages of the disks. The key technology for this approach is to develop various kinds of free-sensors [3]-4]. The active approach is more efficient than the passive. However, the design and cost are normally higher than the hard-disk itself. The second approach is to design the structures of the cases such that impact vibrations can not be transmitted into hard-disks. Hard-disks are isolated by putting viscoelastic materials in between the disks and the cases [5]. Another method is to design air-cushion to absorb vibration energies. Although the passive design is simpler, the performances of vibration isolation are not as good as the active control especially within low frequency ranges.

As comparing the active and passive approaches, the active method needs to access the inside of hard-disks and the controller which might not be possible for system integration companies. The passive method is easier to implement for integration companies, but the performance is quite limited. From this point of view, we propose a different approach that a PZT-based suspension system is designed to achieve active control of hard-disks. This approach can block vibration through the suspension case without going into the inside of the hard-disk.

2. SYSTEM DESCRIPTION

The first criterion for designing the vibration isolation system is that the inner space of the notebook can not be increased especially in the vertical direction. This criterion puts a high constraint on installing the actuator in the vertical direction. Horizontal space is more available within the inside of the notebook. Due to limited space, our idea is to change the connecting hinges of the hard-disk case. The schematic of mother-disk-cases is shown in Fig. 1 where the hard-disk is fixed to the mother board by putting screws on the positions X1, X2, and X3. The vibration energy due to incident drop can only transmit into the hard-disk through the cantilever type bridge as shown in Fig. 1.

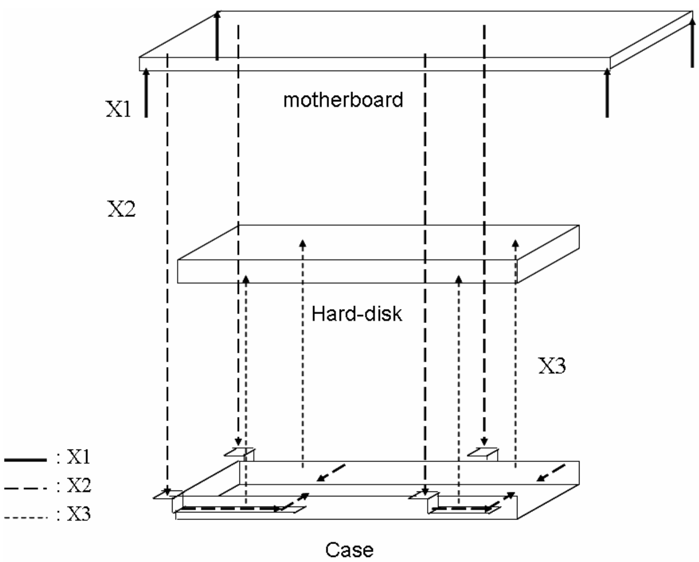

Fig. 1 The schematics of the assembly of the motherboard, hard-disk and case

The idea is that if one can suppress vibrations of the cantilever beam, the force transmission from the motherboard to the hard-disk can be reduced significantly. To achieve this goal, piezoelectric materials are surface bonded on the new hard-disk case as shown in Fig. 2. Four pairs of piezoelectric materials are attached in the cantilevers. Two pairs are used as actuators and two pairs are used as sensors. The piezoelectric sensors are processed by a charge amplifier. The test stand is built to form a PZT based suspension system as shown in Fig. 3.

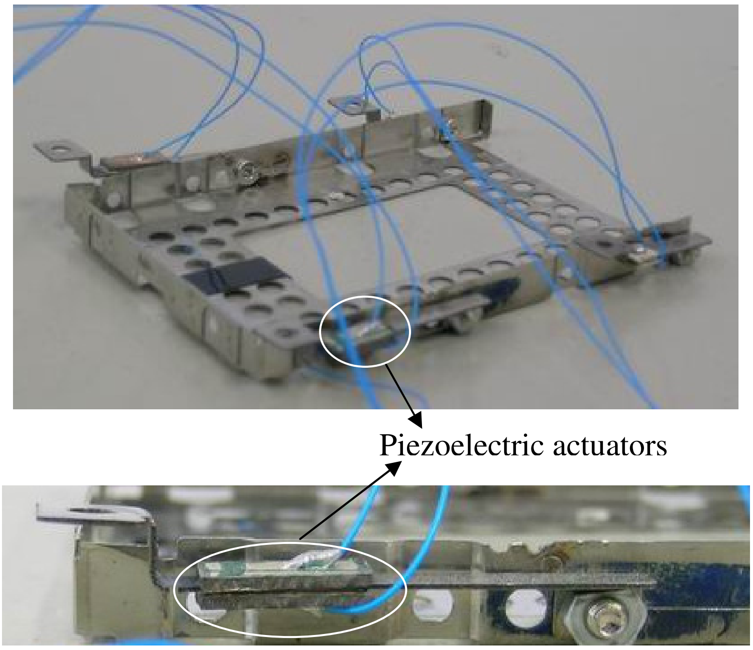

Figure 2. The redesigned case and the piezoelectric actuators

Figure 3 The best stand for the active control of hard disk

Before designing the controller, system identification techniques are applied to obtain the open loop transfer function. The system identification procedure is to generate a chirp sine signal with bandwidth equal to 100 Hz by using an arbitrary function generator. The chirp signal is then amplified to excite the piezoelectric actuators. The chirp signal and the sensor signals are feed into the frequency analyser to obtain the frequency response function. The Bode plot of the open loop system is shown in Fig. 3 where the first resonance frequency is about 42 Hz. The clear plot shows that the feasibility of using piezoelectric materials as sensor and actuators.

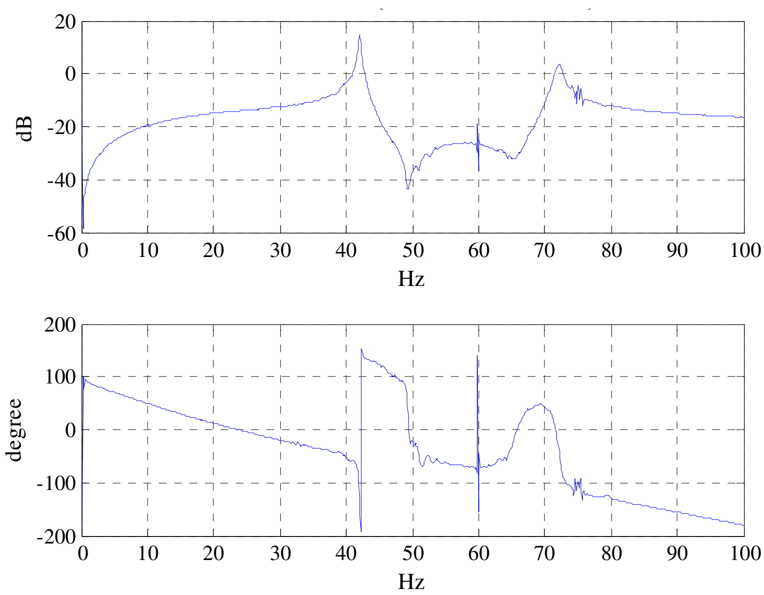

Fig. 4 The Bode plot of the open loop transfer function

3. CONTROLLER DESIGN BASED ON QUANTITATIVE FEEDBACK THEORY

The experimental setup for the closed loop system is shown in Fig. 5. The test bed is set on a table. The impact hammer is used to simulate the force input of the drop test. The PZT actuators and sensors are located at the roots of the cantilever beam. The controller is implemented on a dSPACE control system where Simulink is chosen for controller implementation.

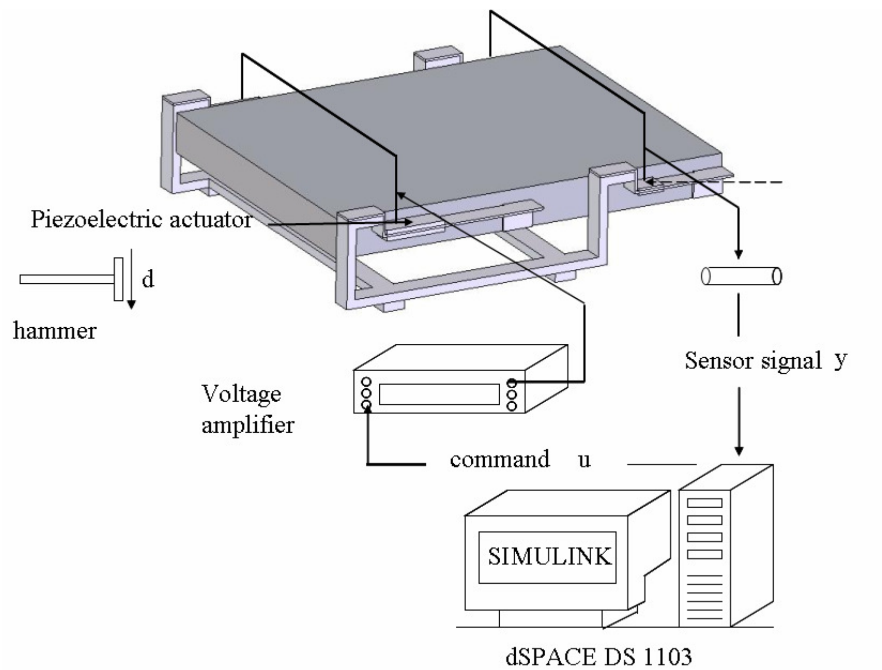

Figure 5. Experimental setup for closed loop control

For the controller design, we choose the QFT controller. Because the QFT is a frequency domain technique, impact disturbance spectrum from the motherboard to the hard-disk can be quite complicated. The QFT not only can include the uncertainties of the plant but also can compensate variation of disturbance forces. The design steps for the QFT controller are quite standard, and are listed as follows [6]:

(a) Bounds for robust stability

The M_L contour is defined to ensure the system can achieve sufficient gain margin and phase margin.

$$\left|\frac{L_3(j\omega)}{1+L_3(j\omega)}\right| \le M_L = 2 \tag{1}$$

where L(jω) is the loop transfer function. The gain margin GM and phase margin PM are related to the M_L by the following equations:

$$\mathrm{GM}=1+\frac{1}{M_L} \tag{2}$$

$$\mathrm{PM}=180°-\theta \text{ ，} \quad \theta=\cos^{-1}\left(\frac{0.5}{M_L}-1\right)\in[0,180°] \tag{3}$$

As long as the loop gain L(s) does not intersect the M_L contour in Nichols chart, one can guarantee at least there is a 30 degree phase margin.

(b) Bound for disturbance rejection

The frequency spectrum of ground disturbance is normally quite low. Here we wish to have an effective disturbance rejection at the region of resonance. The performance specification is set as

$$\left|\frac{Y(jw)}{D(jw)}\right| \le \alpha_M = 0.3\,,\ for\ all\ plant\ P,\ \omega\in[40,45]Hz \tag{4}$$

$$\left|\frac{Y(jw)}{D(jw)}\right| \le \alpha_M = 0.3\,,\ for\ all\ plant\ P,\ \omega\in[70,75]Hz \tag{5}$$

The Nichols chart for the open loop plant and the set bounds are shown in Fig. 6 where the bound for robust stability is marked as 1 and the bound for disturbance rejection is marked as 2.

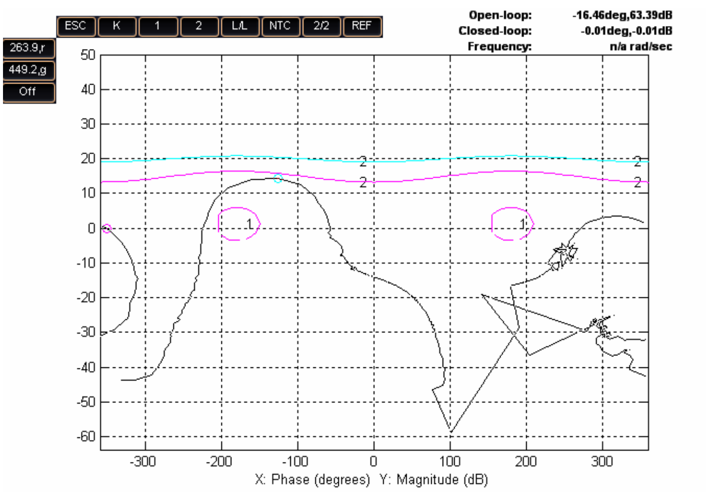

Fig. 6 The Nichols chart of the bound and open loop system

(3) Design the controller

Using the MATLAB QFT toolbox [1994], a sixth order of controller is obtained as:

$$controller = \frac{8.97\times10^{7}\,s^{6} + 8.684\times10^{10}\,s^{5} + 5.577\times10^{13}\,s^{4} + 1.979\times10^{16}\,s^{3} + }{s^{8} + 6398\,s^{7} + 2.016\times10^{7}\,s^{6} + 2.389\times10^{10}\,s^{5} + 1.869\times10^{13}\,s^{4} + } \qquad (6)$$

$$\frac{4.984\times10^{18}\,s^{2} + 6.933\times10^{20}\,s + 6.004\times10^{22}}{7.539\times10^{15}\,s^{3} + 3.52\times10^{18}\,s^{2} + 5.063\times10^{20}\,s + 1.718\times10^{23}}$$

4. EXPERIMENTAL RESULTS

To test the effectiveness of the closed loop system, the impact hammer is used as the disturbance input. The frequency responses of the open loop and closed loop systems are shown in Fig. 7. It is shown that the resonances of the first two modes are reduced more than 20 dB.

The time domain responses of the impact response are shown in Fig. 8. It is shown that the maximum peak of the impact testing is reduced almost by 50% and the settling time of the response is only about 0.3 second which has significant improvement over the uncontrolled case.

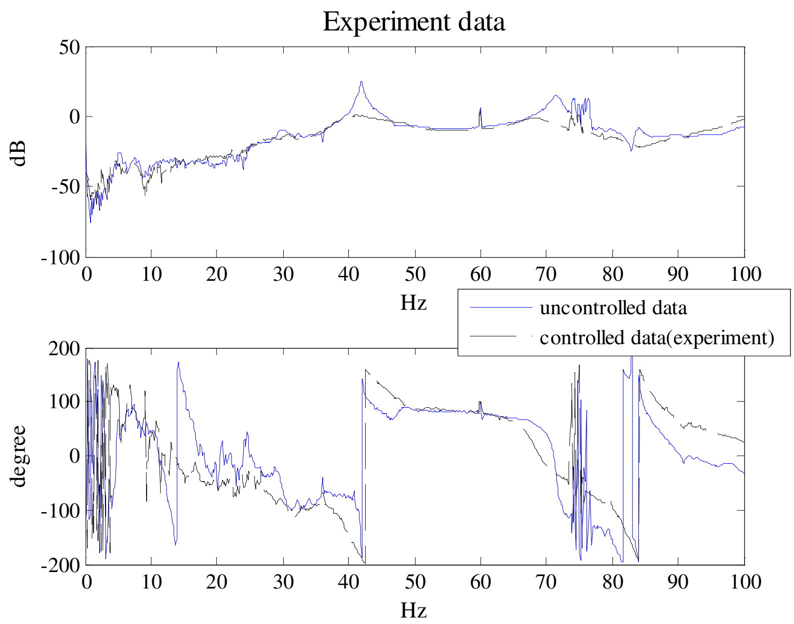

Figure 7 The frequency responses for the open and closed loop systems

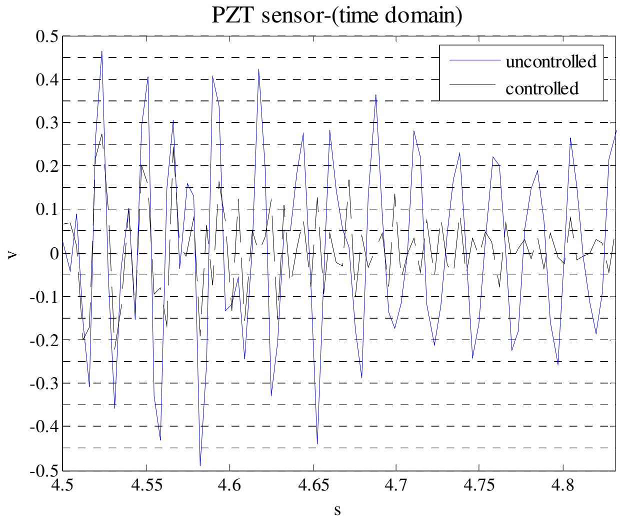

Fig. 8 Time domain response for the impact testing

5. CONCLUSIONS

An active PZT-based suspension system is designed in this paper to reduce the transmission force from the motherboard to the hard-disk. The connecting structure between the hard-disk's case and the motherboard is redesigned such that the piezoelectric actuators can be attached to perform active controls. Experiments are conducted to obtain the frequency response of the plant. Two resonances are found within the control bandwidth of 0 to 100 Hz. The settling time of the impact testing for the closed loop system is reduced to be less than 0.3 second. The maximum peak of the impact testing is reduced by almost 50 % which is hard to obtain for the passive system. The study shows that good vibration isolation can be achieved using piezoelectric actuators.

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