LQG Controller for Active Vibration Absorber in Optical Disk Drive

C. S. Chang[1,2] and T. S. Liu[2]

[1]Electronics and Optoelectronics Research Laboratories, Industrial Technology Research Institute, Hsinchu 31040, Taiwan, R.O.C.
[2]Department of Mechanical Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan, R.O.C.

Unbalanced disks in rotation will lead to the main vibration of an optical disk drive. Passive vibration absorbers are usually used in current optical disk drives to suppress vibration. Generally, optical disk drives have to make a disk spin at multiple speeds by different read/write conditions. However, the passive vibration absorber only suppresses vibration at a specific rotating speed and may excite vibration at other speeds. This paper uses a linear quadratic Gaussian (LQG) controller for active vibration absorbers to reduce disk-drive vibration at multiple rotating speeds. The absorber with LQG control is validated based on simulation and experimental results.

***Index Terms*—Active vibration absorber, Kalman filter, linear quadratic Gaussian (LQG), linear quadratic regulator (LQR), voice coil motor (VCM).**

I. INTRODUCTION

OPTICAL disks, such as CDs and DVDs, are widely used to store various types of information, e.g., text, audio, image, or video data. For multipurpose functions, an optical drive can write or read varied transfer rates and different disks. Thus, an optical disk drive must spin a disk at multiple rotating speeds. Higher storage density disks, including BDs and HD-DVDs, are increasingly required to write movie or dynamic image data because these data are much larger than those with text, sounds, or images. Given this trend, on the one hand, the pits of an optical disk become smaller and track density increases; on the other hand, the rotating speed of an optical disk is also increased for fast data processing. As stated above, vibration at multiple rotating speeds becomes a serious problem to be resolved as storage capacity increases. Of primary concern is how to minimize off-tracking and off-focusing errors in writing and reading data, because such errors degrade the reliability of disk drives. Off-tracking and off-focusing errors can be reduced by servo control when the vibration level of an optical disk drive is relatively low. However, if excessive vibration occurs, overcoming such errors by relying only on the servo without reducing vibration is extremely difficult. Above all, when an unbalanced disk spins, severe vibration may appear, and errors cannot be averted at multiple disk speeds. Heo *et al.* [1] studied a passive dynamic vibration absorber for decreasing the vibration of an optical disk drive at a certain rotating speed. However, vibration was only suppressed at a specific disk speed, while other speeds excited vibration.

Therefore, Chang [2] presented an active vibration absorber, which combines a passive device and an active device, capable of reducing vibration due to an unbalanced disk at multiple speeds. The passive device consists of a mass-spring system, i.e., a conventionally adopted dynamic absorber. The active device is a voice coil motor (VCM). The linear quadratic Gaussian (LQG) controller is regarded by many as the most useful state space controller, and the simplest of many forms of optical controllers. This controller consists of linear quadratic regulator (LQR) and the Kalman filter [3]. The LQR computes state feedback, and the Kalman filter estimates the state vector of a noisy plant. This paper investigates vibration decrease by an active vibration absorber with LQG control at multiple speeds in optical disk drives. The active vibration absorber decreasing effect are presented and compared at multiple speeds in simulation and experimental results.

II. SYSTEM DESCRIPTION

In this paper, the modal analysis technique is employed to obtain simple dynamic models assuming the traverse as a point mass. Therefore, Fig. 1 shows the model of the two D.O.F. system including an active vibration absorber [2], where F is unbalanced force by disks in rotation, and F_L is the Lorentz force of VCM. The active vibration absorber generates controllable force on a traverse and a mass of the absorber for decreasing the vibration of a traverse by the unbalanced force. Fig. 2 shows the block diagram of the feedback control using the LQG controller to suppress vibration. A discrete time state description for this system can be written as

$$x(k+1) = Ax(k) + B_1u_1(k) + B_2u_2(k) + Gv(k) \quad (1)$$
$$y(k) = Cx(k) + w(k). \quad (2)$$

The purpose of the controller is to find control input u_1 that minimize the vibration of a traverse. The unbalanced force can be seen as an external input u_2. Components of the state vector x are an absorber mass displacement, an absorber mass velocity, a

Digital Object Identifier 10.1109/TMAG.2006.888417

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

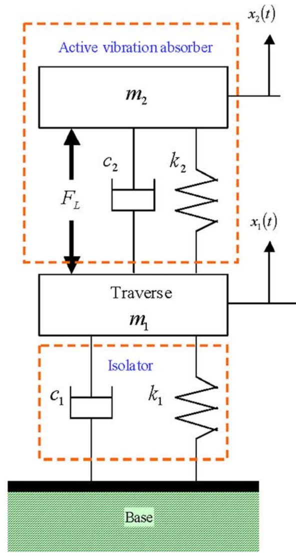


Fig. 1. Model of active vibration absorber [2].

traverse displacement, and a traverse velocity, so the state vector is written as

$$x = \{x_2 \quad \dot{x}_2 \quad x_1 \quad \dot{x}_1\}. \tag{1}$$

However, the traverse displacement is primarily concerned; the C matrix can be defined as follows:

$$C = \{0 \quad 0 \quad 1 \quad 0\}. \tag{1}$$

The Kalman filter is an optical estimator in the sense that it provides the best estimate for the state while rejecting the measurement noise w and plant noise v. $\hat{x}$ denotes the estimate state by Kalman filter. According to LQR optimal control [3], a cost function can be defined as

$$J_{i,N} = \frac{1}{2}\hat{x}^T(N)\,S\,\hat{x}(N) + \frac{1}{2}\sum_{k=i}^{N-1}\left[\hat{x}^T(k)\,Q\,\hat{x}(k) + u^T(k)\,R\,u(k)\right]. \tag{2}$$

Decreasing the vibration of a traverse implies decreasing the cost function. Minimizing cost function is necessary so that the matrices S and Q are positive semi definite, and R is positive definite by Liapunov's second theorem. Therefore, we get the optimal feedback gain K by selecting proper Q and R and saving the S and gain K at each step.

III. Simulation Result

In simulation, the unbalance p is prescribed as 3×10^{-6} kg·m. Thus, the unbalanced force can be calculated by

$$F = p\omega^2 \tag{4}$$

where ω is a rotating disk speed. The other parameters of plant are listed in Table I. Assume the maximum of measurement noises and plant noise are 2×10^{-8}. Fig. 3 shows the vibration condition of a traverse in the time domain by using LQG control at 5000 rpm (≈524 rad/s). The vibration amplitudes are 24.7 μm without control and 2.6 μm subject to control, respectively. The vibration amplitudes decreased results by using LQG control at 1000 to 11000 rpm are shown in Fig. 4. The simulation result has validated the active vibration absorber with the LQG controller.

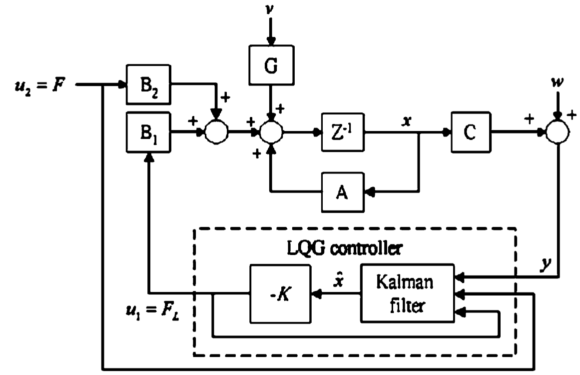


Fig. 2. Block diagram of feedback control using LQG controller.

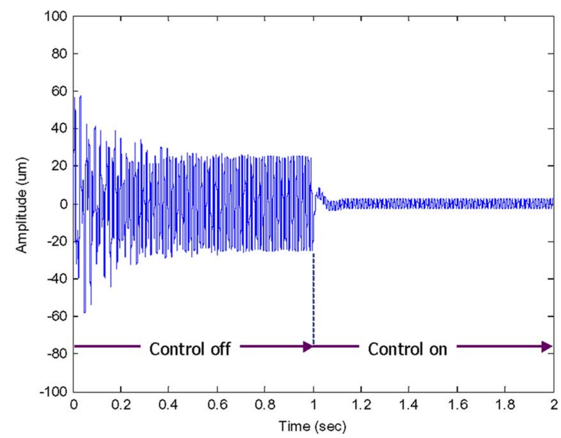


Fig. 3. Simulation result in time domain at 5000-rpm speed.

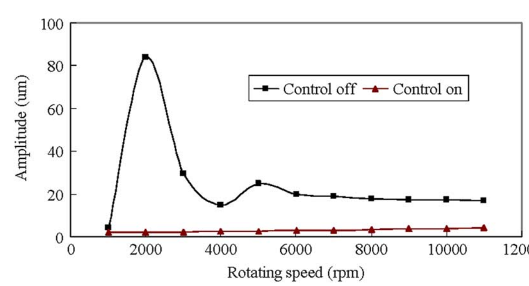


Fig. 4. Simulation results in control on/off at operating speeds.

IV. Experiment

In order to observe the performance of the active absorber in experiments, a personal computer with a data acquisition (DAQ) hardware for the LQG controller, the experimental setup is shown in Fig. 5. The type of a DAQ hardware is National Instrument (NI) PCI-6221. Fig. 6 shows the absorber attached to an optical disk drive and measurement point by vibrometer. In reality, the unbalanced force is variable, whereas the rotating

TABLE I
PLANT PARAMETERS

Symbol	Quantity	Corresponding value
m_1	traverse mass	0.18526 kg
m_2	absorber mass	0.00984 kg
c_1	isolator damping	2.6190 N·s/m
c_2	absorber damping	0.04526 N·s/m
k_1	isolator stiffness	10145 N/m
k_2	absorber stiffness	2000 N/m

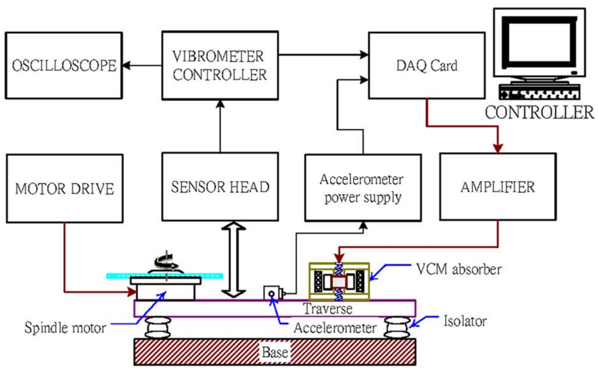


Fig. 5. Experimental setup.

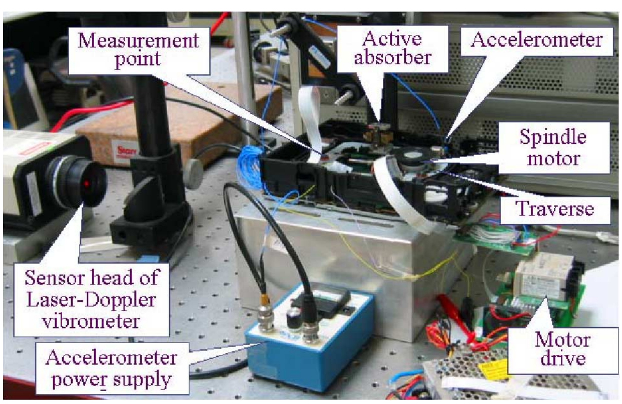
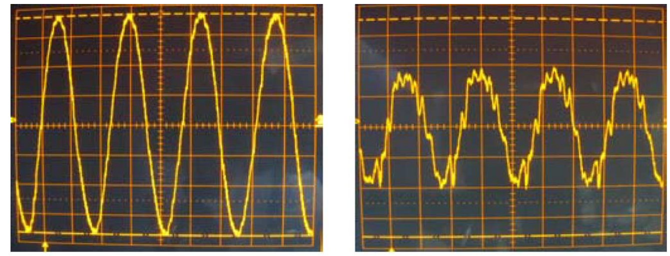


Fig. 6. Photo of experimental setup.

speed is changeable. Quick and stable control is necessary to get the unbalanced force in real time. Therefore, the accelerometer is used to measure the external input u_2, whereas the force is proportional to acceleration and the unbalanced forces in two directions are linear relation. The accelerometer is attached to a traverse in the horizontal direction, as the force of an active absorber does not affect the horizontal acceleration.

Fig. 7 shows the experimental results at 5000 rpm; Fig. 7(a) and (b) are without control and subject to control, respectively. Measured vibration amplitudes and decreased efficiency by LQG control are listed in Table II. The performance of vibration decreases in experiments are not equivalent to simulation results, but the decrease efficiency is 50% at 4000 rpm in an experiment. The sample rate of this control is only 5 kHz and the spindle motor speed is variable in real time, the control resolution and performance could be affected in practice. Therefore, as the rotating speed is higher the decrease efficiency is lower.



(a) (b)

Fig. 7. Measured vibration amplitudes on traverse at 5000 rpm with (a) control off (b) control on.

TABLE II
MEASURED VIBRATION AMPLITUDES AND DECREASE EFFICIENCY

Speed (rpm)	Control off (μm)	Control on (μm)	Efficiency (%)
4000	9.6	4.8	50
5000	35.1	18.2	48
6000	24.0	16.8	30
6980	17.6	12.2	31
8080	16.2	14.8	8
9070	15.5	15.2	2

V. CONCLUSION

In this paper, a VCM is chosen to be the actuator in an active dynamic absorber for decreasing the unbalanced vibration of an optical disk drive at vibration control. A LQG controller provides the control force, thus decreasing the unbalanced force effects on the traverse. According to the simulation and the experimental results, vibrations can be effectively reduced by using this active dynamic absorber. The use of the LQG controller can lead to a quick reduction of the influence of an unbalanced force. The LQG controller achieves a better performance by the regulation at the parameter. From the design viewpoint, the LQG controller has the advantage of being directly perceivable through the senses. However, the employment of the VCM as an actuator can accomplish an effective dynamic vibration absorber in optical disk drives.

ACKNOWLEDGMENT

This work was supported in part by the National Science Council, Taiwan, R.O.C., under Grant NSC93-2752-E009-009-PAE, and in part by the Ministry of Economic Affairs of Taiwan, R.O.C., under Grant 95-EC-17-A-99-R1-0337.

REFERENCES

[1] J. W. Heo, J. Chung, and J. M. Park, "Vibration and noise reduction of an optical disk drive by using a vibration absorber," *IEEE Trans. Consum. Electron.*, vol. 48, no. 4, pp. 874–878, Apr. 2002.

[2] C. S. Chang and T. S. Liu, "Design of adaptive dynamic absorber to reduce optical disk drive vibration at multiple rotating speeds," *Jpn. J. Appl. Phys.*, vol. 40, pp. 1120–1123, 2006.

[3] J. S. Bay, *Fundamentals of Linear State Space Systems*. Singapore: McGraw-Hill, 1999.

Manuscript received August 10, 2006 (e-mail: chishen@itri.org.tw).