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이중 구동 시스템을 위한 압전 밀리엑츄에이터의 제어기 설계

Controller Design of Piezoelectric Milliactuator for Dual Stage System

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Key Words : Dual Stage system, milliactuator, PQ method, servo bandwidth

ABSTRACT

To reach high areal density, less track pitch is expected and more servo bandwidth is required. One approach to overcoming the problem is by using dual stage servo system. In this system, a voice coil motor (VCM) is used as the primary stage while a milliactuator is used as the secondary stage. We have suggested new milliactuator based on the shear mode of piezoelectric elements to drive the head suspension assembly. In this paper, we introduce controller design method, PQ method. PQ method reduces the controller design problem for DISO (dual-input/single-output) systems to two standard controller design problems for SISO (single-input/single-output) problems. The first part of PQ method directly address the issue of actuator output contribution, and the second part allows the use of traditional loop shaping to achieve the overall system performance. This paper shows how to employ the PQ method to meet aggressive close-loop performance specifications for a disk drive system with a VCM and piezoelectric milliactuator.

1. Introduction

The areal recording density of HDD (Hard Disk Drives) has been increasing by about 100% a year. In order to reach high areal density, less track pitch is expected and more servo bandwidth is required. To achieve so high the track density, one possible solution that can provide higher bandwidth is dual stage actuator system.

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The dual stage actuator system consists of a VCM as the primary stage and a milliactuator as the secondary stage. The high bandwidth secondary stage combining with the primary stage will increase the whole system's servo bandwidth, and the high track density is achieved in HDD. Therefore, the precise head positioning control can be realized [5], [8], [9].

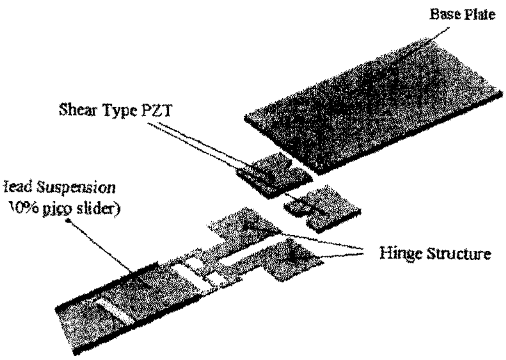
The dual stage actuator system can be classified by energy conversion of location of the secondary actuator. The three types of electrical to mechanical energy conversion methods are electromagnetic, electrostatic and piezoelectric type. Another various types of the dual actuator systems are divide into four groups; moving slider, head, slider, suspension, slider and suspension [10], [11].

In dual stage servo system, only total output of the two actuators is usually available for the servo controller.

Accordingly, the dual stage actuator is a DISO (dual-input/single-output) system, and the servo controller is a SIDO (single-input/dual-output) system. MIMO (multi-input/multi-output) controller is a special case. MIMO controller design method is applied to the design of the dual stage servo system, such as LQR, H_∞, μ-synthesis. However, these control methods are usually results in high order controllers, which are hard to implement on the actual HDD [12].

The master-slave method tries to treat this MIMO design as a series of SISO designs. However, this method assumes that very little interaction takes place between VCM loop and milliactuator loop. Actually, there is an interaction between the two loops, which interfere system performance. The PQ method reduces the controller design problem for DISO (dual-input/single-output) problems systems to two standard controller design problems for SISO (single-input/single-output) problems. The first part of the PQ Method directly address the issue of actuator output contribution as a function of frequency, and the second part allows the use of traditional loop shaping to achieve the overall system performance [1], [2], [3], [4].

In this paper, we use a piezoelectric milliactuator for dual stage systems, as shown in Fig. 1. Our piezoelectric actuator is based on the shear mode of piezoelectric elements to drive the head suspension assembly. The dual servo system is applied PQ method.



Shear Mode Piezoelectric Milliactuator

2. Shear Mode Piezoelectric Millia

2.1 Piezoelectric Suspension

Maintaining the trend towards higher track densit HDD, it is required that track following servo system to increase servo bandwidth for reliable storage devi However, track density increase is limited by serv bandwidths. The system bandwidth is limited by the mechanical resonance of actuator. For increasing mechanical resonance of actuator, piezoelectric suspension that is used secondary actuator of dual actuator system has higher stiffness in the lateral direction and has compliance in the vertical direction. To satisfy these properties, we design channel structure for lateral stiffness, and sidebending height, groove structure for compliance. Also, the hinge structure of the milliactuator is designed on the spring region for adding a vertical flexibility. In addition, we optimize design parameters to trade off between lateral stiffness and vertical flexibility. Due to these efforts, our milliactuator is able to have higher bandwidth and stability of the head/slider. [7]

2.2 New Suspension with Milliactuator

We have suggested new milliactuator base on the shear mode of piezoelectric elements to drive the head suspension assembly. The shear mode of PZT is good characteristic, which is independent of the dimension of the element as shown in Eq. (1).

$$L = n \cdot d_{15} \cdot V \qquad (1)$$

where L is the displacement of the element, n is the number of layers, V is the applied voltage, and d_{15} is the shear mode piezoelectric constant.

As this characteristic, the displacement of shear mode of PZT is not depends on dimensions of the element, but depends on the shear mode PZT type coefficient and the number of layers. [6]

Fig. 2 shows the structure of a piezoelectric milliactuator. The piezoelectric milliactuator consists of a suspension, hinge structure, PZT, and base plate.

The lateral natural frequency of the piezoelectric milliactuator is 10 Hz, which can achieve higher bandwidth about 2 kHz our desired frequency for dual stage actuator systems.

Fig. 2. Milliactuator embedded suspension

3. Controller Design

3.1 Introduction of PQ Method

PQ method is control method that can construct compensator, systematically. PQ method reduces the controller design problem for dual-input/single-output (DISO) systems to two standard controller design problems for single-input/single-output (SISO) problems. The first part of PQ method directly address the issue of actuator output contribution, and the second part allows the use of traditional loop shaping to achieve the overall system performance. Most linear time-invariant feedback systems consisting of a DISO system with a single-input/dual-output (SIDO) compensator can have the block diagram form as shown Fig. 3 [2].

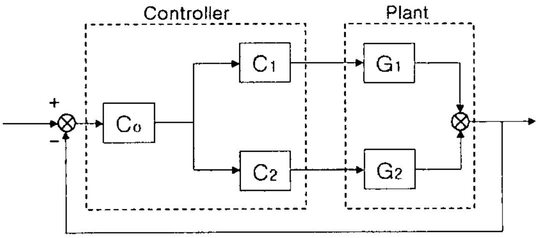


Fig. 3. Block Diagram for general DISO system

G_1 represents the dynamics of the coarse actuator, and G_2 represents the dynamics of the secondary actuator in Frig. 3.

Next step is to define $P = G_2/G_1$. Compensator Q is designed to stabilize the plant (P) with unit feedback as shown Fig. 4. The response of the dual system is dominated by the out put of G_2 until when the frequency is equal to 0 dB crossover frequency. If the outputs are about 180 degrees out of phase when magnitudes are nearly equal, the dual stage system will be interface each other, and total output magnitude will drop considerably owing to destructive interference. To avoid destruction between VCM and milliactuator, a sufficient phase margin should be considered in designing the control scheme.

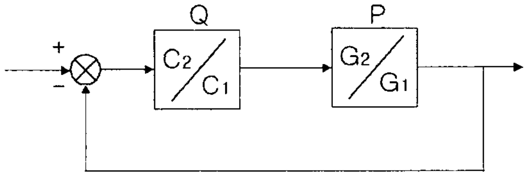


Fig. 4. Block Diagram of the PQ feedback system

Next, C_1 and C_2 is designed to address the issues of stable zeros, relative output, and destructive interference. Once, C_1 and C_2 have been selected, then, $G_{siso} = G_1 C_1 + G_2 C_2$ is defined. If $C_1 = 1$ is settled, the structure of the PQ method is the same as the master-slave method. However, PQ method is clearly considered relative output contribution and the stability of the zeros of the parallel loop.

The design of C_0 is equivalent to design of a compensator for the SISO system in Fig. 5. At this point, the method for the design of the SIDO compensator for the DISO system proceeds as a standard SISO design problem. [3]

Lastly, the compensator C_0 is designed for the parallel system having frequency response G_{siso} with loop shaping technique.

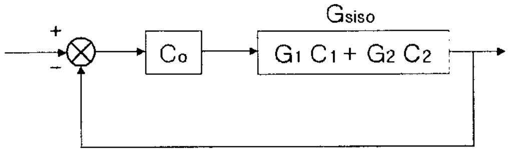
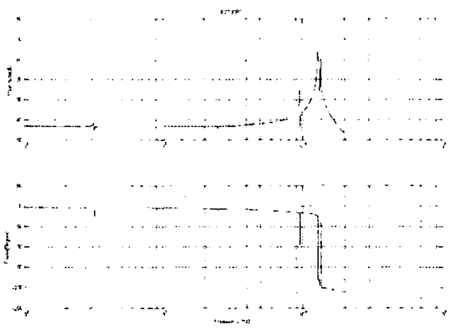


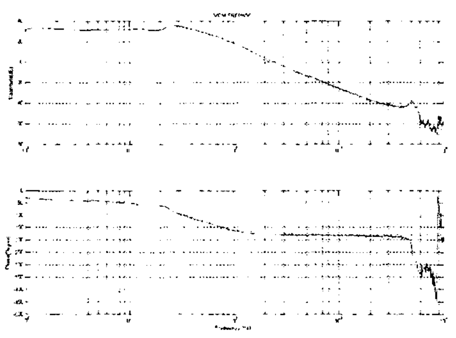
Fig. 5. Block diagram of the SISO system

3.2 Controller Design

Fig. 6 shows the experimentally obtained frequency responses of G_1 (piezoelectric milliactuator) and frequency responses of G_2 (VCM). Dashed line displays a simple modeling for controller design as shown Fig. 6. Then, P is defined as shown Fig. 7(a). The 0 dB, crossover frequency should be chosen some reasons that are based on estimation limits of the runout of the rotating disk at that frequency and saturation limits of the piezoelectric milliactuator. The crossover frequency should be low to achieve large error rejection contribution by using the fine actuator but not so low that the fine actuator is exceeds its range. So, we chose a 250 Hz, 0 dB crossover frequency. The design specifications for systems as follows: 1) zero steady error for a constant disturbance, 2) phase margin is over 30 degree, 3) sensitivity function 0 dB crossover frequency is over 1500 Hz, 4) disturbance rejection at 100 Hz is over 52 dB [2].



(a)

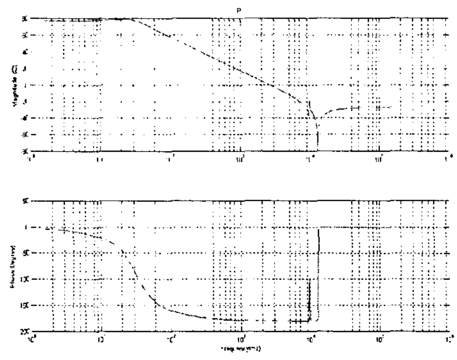


(b)

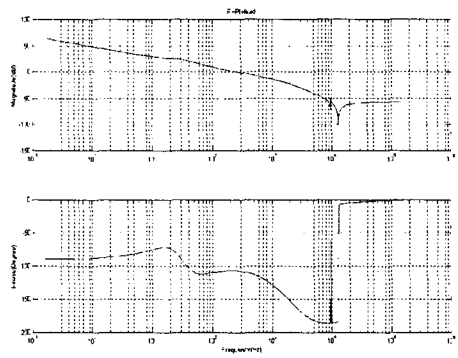
Fig. 6. Frequency response of (a) G_1 and (b) G_2

Fig. 7(a) shows the frequency response of P. The design of Q uses loop shaping techniques with satisfied the design specifications. Q include a PI controller with break frequency at 240 Hz to ensure zero steady state error, and that VCM will dominate the response at low frequency. Q also includes a phase lead compensator to increase phase margin, about 100 degrees at the crossover frequency. As our design specification, the margin of the PQ feedback system is over 60 degrees. Q is :

$$Q = \frac{0.03047s^3 + 1277s^2 + 5.073e005s + 5.061e007}{s^3 + 30000s^2 + 2.25e008s}$$



(a)



(b)

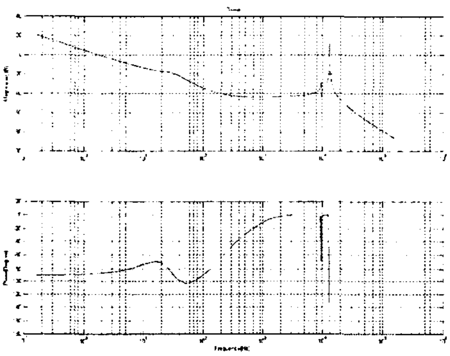
Fig. 7. Bode Plot of (a) P and (b) PQ

Fig. 7 (b) shows the frequency response of PQ. The resulting compensator Q is satisfied with design specification, then $C_1 = 1$, and $C_2 = Q$ is selected.

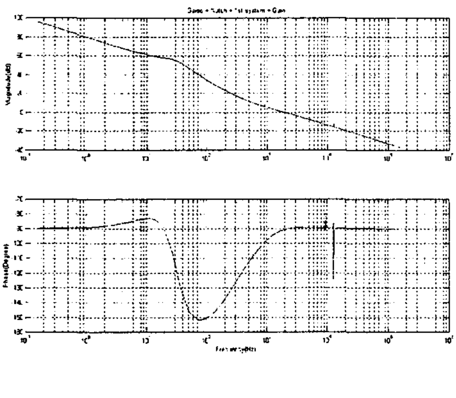
Fig. 8(a) shows the bode plot of $G_{siso} = G_1C_1 + G_2C_2$. The next step is to design C_o. G_{siso} looks like G_2 at low frequency, and also looks like G_1 at high frequency. The objective for the compensator for G_{siso} is to reduce the resonance peaks and obtain desired bandwidth. The cascade of two notch filters and lag compensator is chosen. C_o is to be :

$$C_o = \frac{s^4+435.7s^3+1.022e010s^2+2.29e012s+2.386e019}{1.288e005s^3+8.808e007s^2+4.734e014s+1.657e017}$$

Fig. 8(b) shows the bode plot of $G_{siso}C_o$. The 0 dB crossover frequency is 2 kHz with phase margin of 89.557 degree.



(a)



(b)

Fig. 8. Bode Plot of (a) G_{siso} and (b) $G_{siso}C_o$

Fig. 9 shows the sensitivity function for dual stage actuator system. The 0 dB crossover frequency is about 2 kHz. And its attenuation is 80 dB.

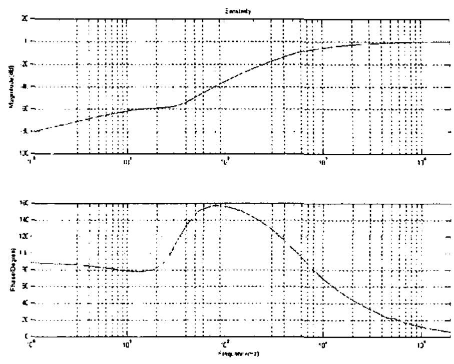


Fig. 9. Sensitivity function

4. Conclusion

This paper shows dual stage actuator system and a developed controller design method, PQ method. Dual actuator system consists of VCM which is used as a primary stage, and milliactuator actuator which is used as a secondary stage. As a secondary actuator, new milliactuator based on the shear mode of piezoelectric elements have been suggested to drive the head suspension assembly. The lateral natural frequency of the piezoelectric milliactuator is 10 Hz. This can make higher bandwidth about 2 kHz, which is desired frequency for dual stage actuator systems.

The PQ method reduced the compensator design from DISO to two SISO problems. The first part of PQ method directly address the issue of actuator output contribution, and the second part allows the use of traditional loop shaping to achieve the overall system performance.

In this paper, the dual stage actuator system has higher bandwidth, 2 kHz, and higher attenuation, 80 dB. There are many approaches for dual stage actuator, and this PQ method is very useful in servo controller design.

Acknowledgement

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