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MODELING AND CONTROL OF A DUAL STAGE ACTUATOR HARD DISK DRIVE

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1. INTRODUCTION

The storage capacity and track density in hard disk drives has increased many-fold in the last decade. The decrease in track width has required an increase in the servo accuracy of hard disk drive suspensions. In order to meet the higher accuracy requirements [1], dual-stage actuators consisting of a conventional voice coil motor (VCM) and an additional micro-actuator for fine-tuning have been proposed.

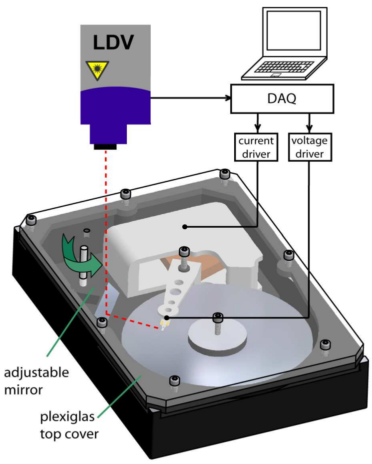

Fig. 1: Experimental setup

In this paper we investigate a commercially available disk drive with a dual stage piezo-electric actuator at the base of the suspension. The actuator dynamics are modeled and a controller design is performed.

2. MODELING AND SYSTEM IDENTIFICATION

In order to be able to inject control signals, the hard disk drive servo controller is bypassed completely. The circuit board was disconnected from the HDD and all motor drivers were replaced. Since the position error signal (PES) of the servo mechanism is not available directly, a laser Doppler vibrometer (LDV) is used to measure the radial slider motion. The experimental set-up is shown in Fig. 1. A Plexiglas top cover and a mirror enable the focusing of the laser beam onto the side of the slider.

The frequency response function (FRF) of both actuators was determined and used to compute the impulse response via inverse discrete Fourier transform. A discrete-time model of the dual-stage actuator is estimated using the eigensystem realization algorithm [2]. An additional frequency-dependent weighting is used to emphasize control relevant resonance modes of the actuator response. The modeling procedure used in this paper has been previously reported in [3] und [4]. The measurements and the estimated models of both actuators are depicted in Fig. 2.

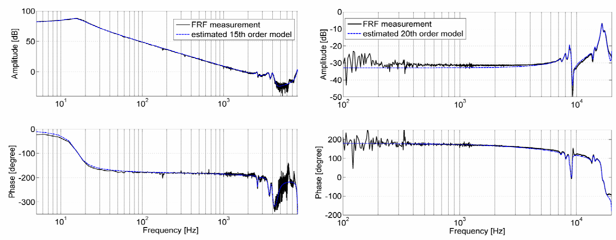

Fig. 2: FRF and estimated model of VCM (left) and PZT (right)

3. CONTROLLER DESIGN

Two different controller design techniques were applied. The sensitivity decoupling method (SDM) [5] allows a separate controller design for the VCM and the PZT. The control structure is given in Fig. 3.

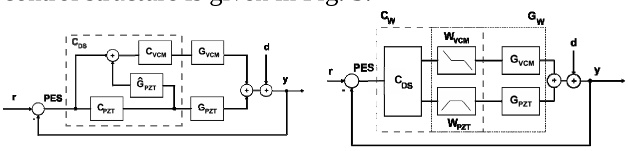

Fig. 3: Control structure of SDM controller (left) and H∞ loop shaping controller (right)

The displacement of the PZT is estimated using a simplified PZT model. C_{PZT} is designed as a band pass filter including a notch filter to suppress the micro-actuator (sway) mode at 17 kHz. Thereafter C_{VCM} is designed containing a low pass filter approximating an integrator, a second order lead lag compensator and a high frequency roll-off. The dual-stage controller is depicted as the solid lines in Fig. 4 where the left plot shows the VCM controller and the right plot shows the micro-actuator controller.

In addition, a combined approach is applied that uses loop shaping and H_∞ optimal control design [6]. Figure 3 (right) shows the main principle. First, weighting filters

W_{VCM} and W_{PZT} are designed for both actuator models that represent the shape of the optimal controllers to be estimated. Then, a 4-block H_∞ control problem is formulated and used to minimize control signal peaking and error rejection peaking. Given the optimization constraints, an optimal controller C_{DS} is computed. Finally, the weighting filters are preserved in C_{DS}. A 10^{th} order stable approximation (dashed lines in Fig. 4) was obtained after applying a closed-loop reduction routine.

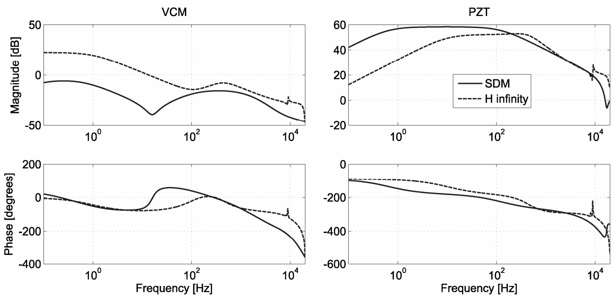

Fig. 4: Dual stage controller

To evaluate the performance of the controllers, the closed loop feedback connection is simulated by using a step of 100nm as an input representing either a high frequency disturbance or a short track seek. Figure 5 shows the simulated individual distribution of the VCM and the PZT to the total displacement of the read/write head. Several performance measures are given in Tab. 1.

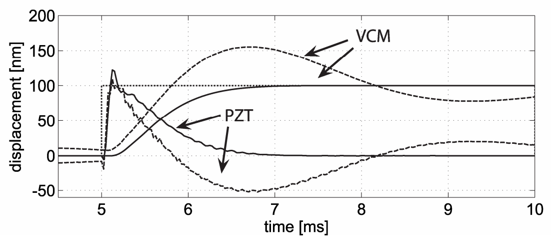

Fig. 5 Simulated displacements for SDM (solid) and H∞ controller (dashed)

Table 1 Comparison of controllers

	SDM	H_∞
gain margin [dB]	6	6
phase margin [°]	54	35
overshoot [%]	22	20
10% settling time [ms]	0.175	0.275
crossover frequency [kHz]	2.37	2.32
max control signal VCM	5 mV	10 mV
PZT	5.1 V	4.7 V

4. CONTROLLER IMPLEMENTAION

Both controllers were implemented at a sampling frequency of 40 kHz. A 100 Hz square wave with 100nm peak to peak value was applied as a reference signal. Time based averaging was applied and the averaged response for the both controllers is shown in Fig. 6.

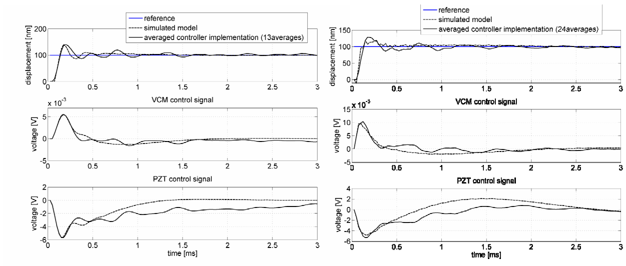

Fig. 6: Implemented SDM controller (left) and H∞ loop shaping controller (right)

5. CONCLUSION

A discrete-time modeling algorithm based on frequency response function measurements was proposed. Two different dual-stage controllers were designed using classic loop shaping techniques combined with modern H_∞ control problem algorithms. Both controllers showed similar servo performance. However, the H_∞ loop shaping controller shows a better disturbance rejection in the low frequency regime.

Both, model estimation and H_∞ loop shaping controller design can be implemented in the hard disk drive firmware. Since actuator dynamics could be a function of tolerances during manufacturing, the drive could perform a controller calibration itself, and, thus, could improve the servo performance and the track misregistration (TMR) budget.

The different controllers designed in this study were implemented in the HDD and showed a stable feedback control. Small differences between measurement and simulation were observed that are caused by repeatable disturbances.

REFERENCES

[1] Mori, K., Munemoto, T. et al., A Dual Stage Magnetic Disk Drive Actuator Using A Piezoelectric Device for a High Track Density, *IEEE Trans. on Magn*., vol. 27(6), 1991, pp.5298-5300

[2] Juang, J.N., Pappa, R.S., Eigensystem realization algorithm for modal parameter identification and model reduction, *Journal of guidance, control, and dynamics*, vol. 8, issue 5, p620, 1985

[3] Claes, M. Graham, M.R., de Callafon, R.A., Frequency domain subspace identification of a tape servo system, *Springer Microsystem Technologies*, 2007 13: 1439-1447

[4] Boettcher, U, Raeymaekers, B, de Callafon, R.A., Talke, F.E., Dynamic modeling and control of a piezo-electric dual-stage tape servo actuator, *IEEE Transactions on Magnetics*, accepted for publication Jan 2009

[5] Horowitz, R. et al, Dual-stage servo systems and vibration compensation in computer hard disk drives, *Control Engineering Practice*, vol. 15, 2007, pp. 291-305

[6] Bongers, P.M.M., Bosgra, O.H., Low Order Robust H∞ Controller Synthesis, *Proceedings of the 29th Conference on Decision and Control*, Honululu, Hawaii, 1990