DESIGN OF A DUAL STAGE ACTUATOR TAPE HEAD CONTROLLER

Uwe Boettcher*, **Bart Raeymaekers, Raymond A. de Callafon, Frank E. Talke.**

University of California, San Diego
Center for Magnetic Recording Research
9500 Gilman Drive, La Jolla, CA 92093-0401, U.S.A.
uboettch@ucsd.edu

Introduction

As storage density in magnetic tape drives increases, the requirements on the track following servo mechanism become more challenging. In state-of-the-art tape drives a voice coil motor is used to reject disturbances such as lateral tape motion (LTM). A schematic of a typical tape transport is shown in Fig. 1. LTM is defined as the motion of the tape perpendicular to the tape transport direction. The relative lateral position of the read/write elements with respect to the tape is determined by prewritten servo tracks on the magnetic tape. Using the VCM, the read/write head attempts to follow the LTM. However, since the available control signal level is limited in the tape drive, the bandwidth of the servo controller is limited. As a result, high frequency LTM cannot be followed by the servo actuator and track misregistration might occur.

A novel design of a dual-stage actuator tape head was implemented by Raeymaekers et al. [1]. This design consists of a state-of-the-art commercial tape head that was modified to include a piezo-based piggyback actuator (PZT). The PZT only actuates the air bearing surface and allows increasing the servo bandwidth beyond 500 Hz, which is typically achievable with a VCM actuator, while decreasing the magnitude of the control signal.

Experimental set-up and system modeling

Since our prototype has no read/write ability, we use a Laser Doppler Vibrometer (LDV) to detect the lateral position of the air bearing surface. Figure 2a shows the schematic of the experimental set-up. Figure 2b shows the model of the dual-stage actuator G. G_{VCM} and G_{PZT} represent a model of the VCM and the PZT, respectively. The signals u_{VCM} and u_{PZT} denote the system input whereas y_{LDV} denotes the system output, which is the position of the air bearing surface.

*Corresponding author: Uwe Boettcher

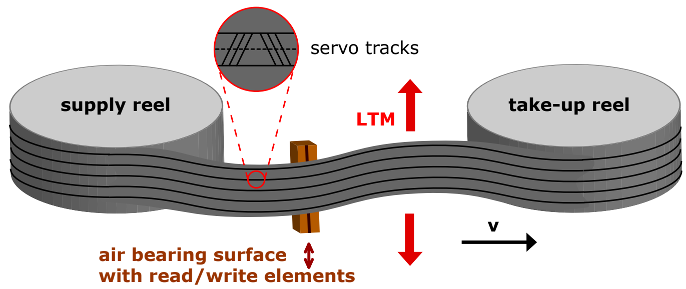

Figure 1. Schematic of a typical tape transport

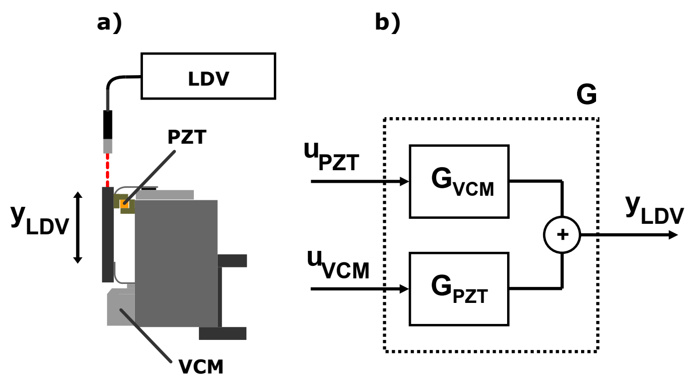

Figure 2. a) Schematic of the dual-stage actuator prototype b) Dual-input single-output model.

Experimental data and system identification are used to obtain a discrete time model. The Generalized Realization Algorithm (GRA) proposed by de Callafon [2] allows the direct estimation of a discrete time model based on step response measurements and is related to the Ho-Kalman algorithm [3]. The measured data are stored in a Hankel matrix construction. The matrix is decomposed using singular value decomposition which allows to specify the effective rank, and, thus, the order of the model. The state space matrices can be extracted using the controllability and observability matrices. The model order was chosen to be 30, and, thus, high enough to capture most of the system dynamics of both, the VCM and the PZT.

The result of a frequency domain validation with a dynamic signal analyzer is shown in Fig. 3. We observe good agreement between the measured FRF and the estimated model.

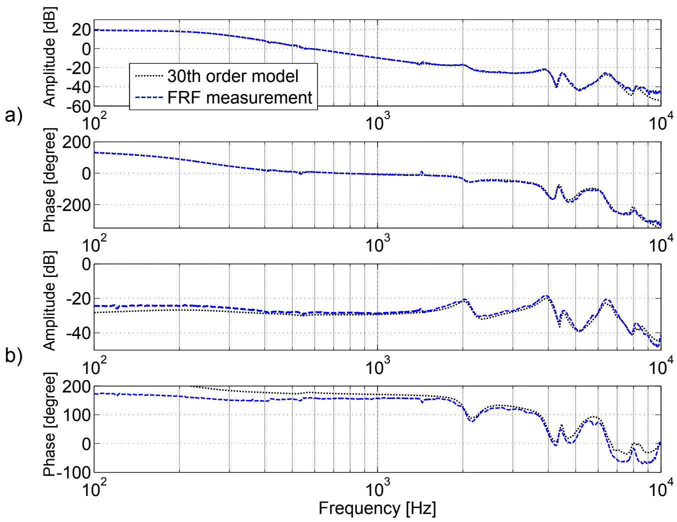

Figure 3. Frequency domain validation a) voice coil motor and b) micro-actuator

Dual-stage controller design

In our experimental set-up, the relative motion between the two actuators is unknown since we only use one position measurement that includes the contribution of the VCM and the PZT, respectively. The system is considered as a dual-input single-output system (DISO).

The servo control structure for the dual-stage actuator tape head is shown in Fig. 4. The signal e is the difference between the desired lateral position of the tape head r and the actual lateral position of the tape head y. The controller design is based on the PQ method which was first proposed in [4] and applied to a dual stage controller in hard disk drives in [5]. The PQ method allows to decompose a DISO system into two SISO systems and frequency separation between the actuators can be achieved. That means, that the PZT attempts to follow the high frequency LTM, while the VCM is used to reject low frequency disturbances. C_{VCM} and C_{PZT} are the VCM and micro-actuator controllers. G_{VCM} and G_{PZT} represent the dynamics of both actuators.

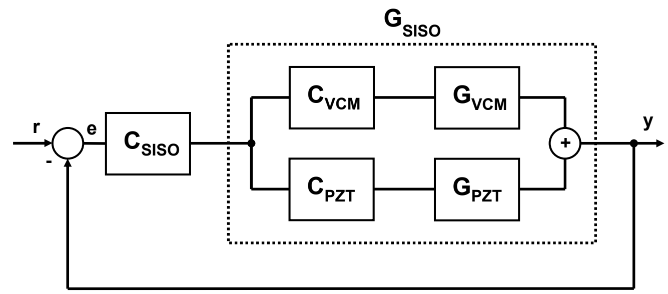

Figure 4. Dual-stage actuator tape head control design

The VCM controller C_{VCM} is given in (1). It contains an integrator to remove the steady-state error and reject disturbances. A second order lead compensator increases the phase margin and ensures stability in the feedback loop. The micro-actuator controller given in (2) is designed as a high pass filter, since it only needs to respond to LTM frequencies above several hundred Hertz.

$$C_{\mathrm{VCM}} = \frac{(z-0.8966)}{(z-0.999)} \cdot \frac{(z-0.9687)^2}{(z^2-1.31z+0.6289)} \quad (1)$$

$$C_{\mathrm{PZT}} = 7.43 \cdot \frac{(z-0.999)}{(z-0.7789)} \quad (2)$$

In order to achieve closed-loop stability and high performance of the overall system, the controller C_{SISO} is implemented. Several notch filters were used to cancel out high frequency resonance modes.

We have compared the performance of our dual-stage controller to a single-stage controller C_{ss}, which only uses the voice coil motor. The controller was designed to achieve about the same performance as the dual-stage controller. The system parameters for both designs are listed in Table 1. Even though the closed loop bandwidth of the dual-stage design is approximately 25% larger than in the single-stage design, the main advantage of the dual-stage design can be seen in Fig. 5. The magnitude of the control signal of the VCM in the dual-stage design is approximately three times smaller than in the single-stage design, for the same displacement. Hence, the dual-stage controller can reject disturbances with larger amplitudes than the single-stage controller.

Table 1. System parameters

	Single-stage	Dual-stage
gain margin	6dB	6.8 dB
phase margin	42 degrees	48 degrees
overshoot	33%	21%
5% settling time	1.1 s	0.8 s
closed loop bandwidth	≈ 800Hz	≈ 1kHz

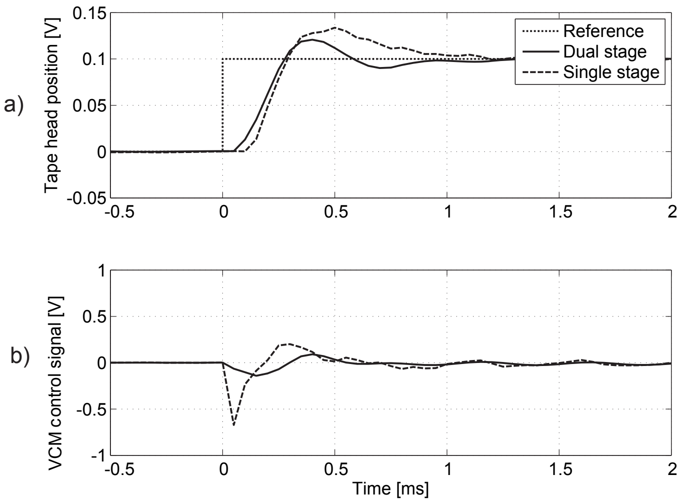

Figure 5. Simulated step response for dual-stage and single-stage control design

Controller implementation

The dual-stage controller was implemented in the dual-stage actuator tape head prototype. We have applied a 100 Hz square wave reference signal of 0.1 V amplitude illustrated by the dotted line in Fig. 6a. The control signal for the VCM and the PZT are shown in Fig. 6 b and c, respectively.

From Fig. 6, we observe that the dual-stage controller settles the lateral position of the tape head to the desired (reference) position within less than 1 ms. The simulated output signal and the two simulated control signals are in very good agreement with the measurements.

Discussion and conclusion

A dual-stage controller for a dual-stage actuator tape head has been designed and implemented. The dual-stage design uses less control energy than a comparable single-stage design. Thus, it enables rejection of disturbances with larger amplitudes. The estimated model shows an excellent agreement with the measured results.

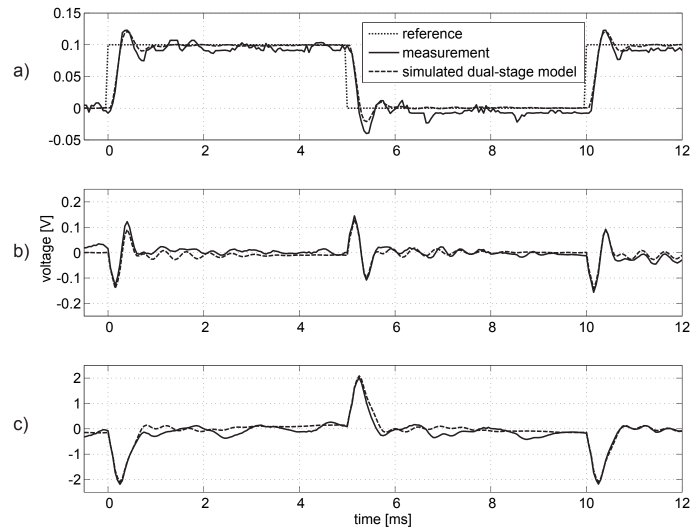

Figure 6. Implemented controller

Furthermore, we have achieved an improvement in the closed loop bandwidth. A different mechanical design with a stiffer second stage would move some of the low frequency resonance modes in the frequency response function to a higher frequency, and, thus, would allow a larger closed loop bandwidth.

References

[1] Raeymaekers, B., Graham, M.R., de Callafon, R.A., Talke, F.E., 2007, *Design of a dual stage actuator tape head width high bandwidth track-following capability*, Proceedings of ASME Information Storage and Processing Systems Conference, Santa Clara, CA, USA

[2] de Callafon, R.A., 2003,*Estimating parameters in a lumped parameter system with first principle modeling and dynamic experiments*, Proceedings of 13th IFAC Symposium on System Identification, 1613 - 1618, Rotterdam, the Netherlands

[3] Kalman, R.E., Ho, B.L.,1966, *Effective construction of linear state-variable models from input/output functions. Regelungstechnik*, 14:545 548

[4] Schroeck, S.J., Messner, W.C., 1999, *On controller design for linear time-invariant dual-input single-output systems*, Proceedings of the American Control Conference, San Diego, CA, USA

[5] Graham, M., Oosterbosch, R.J.M., de Callafon, R.A., 2005, *Fixed order PQ-control design method for dual stage instrumented suspension*, IFAC Congress, Praha, Czech Republic