

Enhanced Vibration Suppression In HDDs Using Instrumented Suspensions

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Abstract—High resolution thin film strains sensors have been successfully integrated into instrumented suspension prototypes, and utilized in an operating experimental disk drive. Realistic plant and disturbance models were obtained from experimental data. Multi-rate, nominal H_2 control synthesis was then utilized to investigate closed-loop vibration suppression. Simulations demonstrate improved tracking performance with auxiliary high-resolution, high-rate strain sensing.

Index Terms—hard disk drive servos, piezoelectric thin films, multi-rate control, H_2 control

I. INTRODUCTION

Industry goals for magnetic recording technology are currently in the terabit per square inch regime. Such ultra-high data density requires a multi-faceted approach to hard disk drive (HDD) servo solutions. Dual-stage actuation has been extensively studied and advanced actuation schemes are currently being deployed in disk drive products. However, sensing technology is another important feature of the servo system that has been less developed.

In a conventional HDD the position error signal (PES) is obtained by reading dedicated servo tracks permanently encoded onto the disk. Thus, the PES sampling rate is fixed, limiting detection of high frequency disturbances such as airflow-induced vibrations. Bulk PZT-actuated suspensions have been modified to provide sensing information [1, 2]. However, this limits the placement and sensitivity of the sensors. We previously demonstrated fabrication and implementation of thin-film sensors directly onto a suspension structure, decoupling the design of actuators and sensors [3]. Here, we make use of multi-rate, nominal H_2 control synthesis to demonstrate the

benefits of using such sensors in conjunction with the PES.

II. SENSOR DESIGN AND FABRICATION

Figure 1 illustrates the instrumented suspension used in the experiments. Sensor location and shape were designed using an efficient optimization methodology based on linear quadratic gaussian (LQG) control. In this way, the sensor configuration was optimized with respect to a cost function that captures closed-loop disturbance attenuation. The details of the algorithm are given in [4]. The algorithm was implemented by using a finite element (FE) model of the suspension assembly to obtain the plant and sensor models used in the LQG minimization.

Piezoelectric ZnO thin film was selected for the sensor material because its relatively low processing temperature is compatible with the steel wafers used to fabricate suspensions. ZnO was deposited using RF magnetron sputtering, and aluminum was used for the electrode material. Details of the fabrication process and film characterization can be found in [3].

III. EXPERIMENTAL TESTING

A circuit was designed to amplify the picoamp-level strain signals in the frequency range of 1 kHz and 30 kHz. Overall nominal gain of the amplifier was 1000. To reduce interference from the nearby spindle and VCM signals the amplifier circuit was installed directly onto the E-block using surface mount components.

Open loop transfer functions were obtained with the head flying on a spinning disk in an experimental HDD. Off-track displacement was obtained using a laser Doppler velocimeter (LDV).

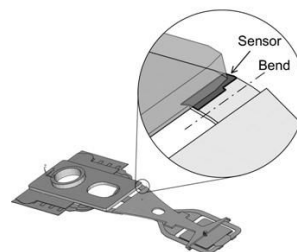


Fig. 1. Illustration of the instrumented suspension prototype.

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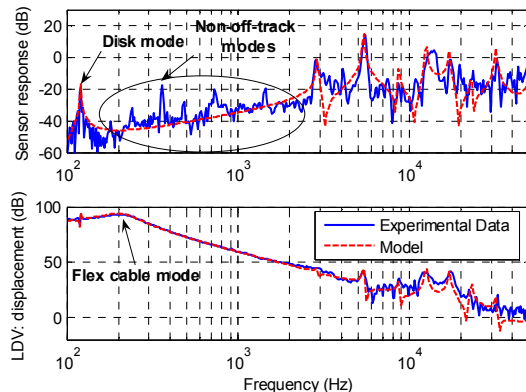


Fig. 1. Frequency response magnitude, from the VCM excitation to the strain sensor (top) and LDV (bottom) outputs.

These transfer functions are shown in Fig. 2. The sensor detected the same modes that appear in the LDV off-track displacement measurement. In addition, it was more sensitive to higher frequency modes, and picked up some lower frequency modes that were attributed to non-off-track displacement. The measurement of the windage excitation is shown in Fig. 3.

III MODELING AND SIMULATIONS

A MIMO state space model captured the plant dynamics. The magnitude responses of the models are shown in Fig. 2. In the model of the sensor response, non-off-track modes were ignored, since it is assumed that symmetrical, interconnected sensors can be hard-wired to cancel these modes [3]. A number of other modes were neglected in the interest of keeping the order of the controller manageable. Track runout was not considered in these simulations. Windage disturbance was modeled as a white noise input with appropriate scale factors for each mode. The windage model is shown in Fig. 3. Sensor noise was estimated to be 50 mV, and PES noise was assumed to be 1 nm. The PES sample rate was 30 kHz.

Multi-rate, nominal H2 control was used to evaluate the benefits of high-rate strain sensing. We employed a numerical algorithm which uses a lifting technique to transform the periodic time varying H2 synthesis problem into a linear time invariant problem [5]. Furthermore, the algorithm efficiently incorporates multi-rate variance constraints on values such as control input. In this way, the optimization directly minimized PES variance instead of a weighted sum of several values. VCM input was limited to 5 V at 3σ . In the simulations, the strain sensing was sampled N times as fast as the PES, where $N = 1, 2, 4$. Results are shown in Table 1.

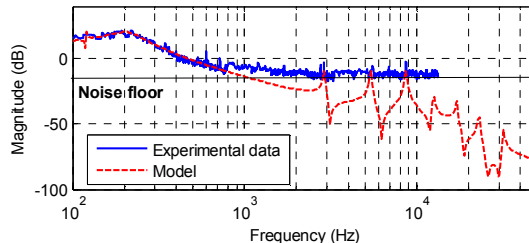


Fig. 3. Windage frequency response. Note that the LDV noise floor is about .1 nm.

TABLE I
CLOSED-LOOP SIMULATION RESULTS

	PES, 3σ (nm)	VCM Input, 3σ (V)
$N=0$ (PES only)	5.6	5
$N=1$	5.1	5
$N=2$	4.7	5
$N=4$	4.4	5

PES rate is 30 kHz, and the open loop 3σ value is 199 nm.

By adding strain sensing at the same rate as the PES, the 3σ error decreased from 5.6 to 5.1 nm, indicating that the improved sensitivity of the strain sensors alone is beneficial. Then, by increasing the sample rate of the strain sensors, error is further reduced to as low as 4.4 nm.

IV. CONCLUSIONS AND FUTURE WORK

Simulation results showed that auxiliary high-resolution strain sensing can expand the bandwidth of a close-loop vibration suppression controller in a multi-rate framework. Such sensing will be critical for achieving sub-nanometer control beyond the capabilities of current HDD servos. It should be noted that nominal H2 control is useful for hardware evaluation, but lacks the robustness suitable for actual implementation. Furthermore, using only the VCM limits the precision of the servo. Future work will investigate more sophisticated multi-rate control schemes that exploit the auxiliary strain signal, as well as dual-stage actuation.

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