Dual-Stage Actuator

Overview

To increase hard disk drive (HDD) data density, the size of bits – the 1s and 0s that represent the information stored on the disk – decreases and the spacing between their concentric tracks shrinks. As these dimensions shrink, it becomes more difficult to position the read-write head’s transducer element over the center of the data track.

Outside disturbances – even vibrations from music played through built-in laptop speakers — can cause head-track misalignment.

Conventional mobile HDDs use only one actuator, a voice coil motor (VCM), to position the read-write head. This is like trying to write with a rigid wrist and fingers. To hit the ever-smaller moving targets, HGST is now using a dual-stage actuator (DSA). The second stage acts like your wrist and fingers, allowing you to position your pen accurately. If you think of it like driving on a curving, multilane highway, the first-stage actuator puts you on the highway, and the second, fine-tuning stage keeps you centered in the correct traffic lane.

HGST has implemented a DSA in the Travelstar® 5K1500 mobile drive to improve head-positioning accuracy for better performance, data integrity and overall drive reliability. HGST has also implemented DSA technology in the Travelstar Z5K1000 mobile drive.

Structure and Mechanical Characteristic

As mentioned, previous generation 2.5-inch HDDs use a single VCM to position the read-write head. The actuator’s arm and suspension, which extends from the VCM to the read-write head, can swing the head from the load/unload ramp beyond the disk’s outer diameter to the inner-diameter data track near the central motor hub. The relatively large mass of the head stack assembly results in a relatively low vibrational resonance frequency, which makes accurate head positioning over high-density tracks or with external vibrations very difficult and slow.

The DSA implemented in the Travelstar 5K1500 and Z5K1000 consists of conventional VCM first stage and a Milli-actuator (MA) second stage located about near the tip of the suspension (Figure 1). The MA has two piezoelectric actuators (Lead Zirconate Titanate (Pb(Zr,Ti)O₃, or PZT) attached to the suspension’s baseplate in a robust design.

Figure 1: Milli-actuator suspension structure and actuation
When voltage is applied to the MA, one piezo element expands as the other contracts. This action causes a slight – less than one millionth of a meter -- but exquisitely controlled motion of the read-write head. Since the MA's stroke at the head element is so short and the moving mass so small and light, this element's vibrational resonance frequency is much higher than that of the VCM single-stage actuator. As a result, the DSA can rapidly and accurately position the head element over the correct data track.

The MA's transfer function from the drive voltage to the head displacement is shown in Figure 2. This function improves servo bandwidth to higher than 3kHz and improves head positioning accuracy.

Figure 3 shows the schematic dual-stage servo block diagram with VCM and MA. The block diagram consists of VCM, MA, VCM controller and MA controller. "Pv" and “Pm" are the plant of VCM and MA, respectively. The MA controller consists of compensator “Cm” and MA model “Pm0”. The signal “pes” represents the position error signal, and “r” represents track runout. The “vpe” and “mpe” are respectively the position error of VCM and MA. Then the overall position error “pe” is the sum of “vpe” and “mpe.” The total dual-stage open loop transfer function from “pes” to “pe” is:

\[ G_{ol} = P_m \cdot C_m + (1 + P_{m0} \cdot C_m) \cdot P_v \cdot C_v \]

And the error rejection closed loop TF from “r” to “pes” is:

\[ \frac{1}{1 + G_{ol}} = \frac{1}{(1 + P_m \cdot C_m)(1 + P_v \cdot C_v)} = G_{snsvcm} \cdot G_{snsma} \]

where \( P_{m0} = P_m \).

The total error rejection closed loop “Gerr” of the dual-stage servo system is the product of the VCM and MA loop sensitivities, “Gsnsvcm” and “Gsnsma”, respectively. Thus, the dual-stage servo control design can be decoupled into two independent controller designs; the VCM loop and the MA loop. Usually, the VCM open loop gain-crossover frequency is limited by the head-stack assembly and suspension resonance modes to be between 1,500 to 2,000Hz. The dual-stage compensator is defined by the design of the MA compensators that attains additional attenuation of “Gsnsma.”
Figure 4 shows the position error signal with DSA servo activated (blue) compared to the single-stage VCM servo (black), both acting in the presence of external vibrations. The blue line shows how significantly the DSA can cancel out the head-position oscillations that occur when only a single-stage actuator is used.

Dual-stage, High-bandwidth Servo Improves Performance

The DSA high-bandwidth servo leads to a noticeable improvement in performance.

Figure 5 shows the performance evaluation of Travelstar 5K1500 in notebook PCs in two conditions: 1. with sound muted and 2. with speakers making sound. For each condition, we compare the DSA servo system to a conventional single-stage VCM servo system (which includes Rotational Vibration Safeguard (RVS)).

The single-stage VCM servo with RVS maintains relatively good performance in the PC System-A, while it could only score 37 percent in the PC System-B. The performance of the VCM with RVS shows good rejection of oscillation due to rotational vibration (RV), which can be detected by two shock sensors of RVS. On the other hand, DSA shows the benefit in both cases.

These benchmark results confirm that the DSA assembly constitutes a major step forward in HDD technology. DSA gives users better and more reliable performance.

![Figure 4: Position error signal DSA activated compared to DSA inactivated](image)

![Figure 5: System level performance comparison of Dual Stage Actuator (DSA) vs, Single Stage with RVS under speaker vibration](image)