Microactuator for High-Capacity Hard-Disk Drives

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Disk Drives in the past
(IBM, 60 GB storage, 1980-1989)

Today:
400 GB
Hitachi Deskstar 7K400
Recording Density Growth

HGST Areal Density Perspective

- Superparamagnetic effect
- 1st MR Head
- 1st AFC Media
- Travelstar 80GN
- Deskstar 180GXP
- Travelstar 30GN
- Microdrive II
- 1st AFC Media
- Travelstar 80GN
- Deskstar 180GXP
- Travelstar 30GN
- Microdrive II
- 1st AFC Media
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- Travelstar 30GN
- Microdrive II

- IBM RAMAC (First Hard Disk Drive)
- Ultrastar 146Z10
- 100% CGR
- 60% CGR
- 25% CGR
- 35 Million X Increase

Production Year

- 1960
- 1970
- 1980
- 1990
- 2000
- 2010

Areal Density Megabits/in²

- 10^3
- 10^4
- 10^5
- 10^6

HGST Disk Drive Products
Industry Lab Demos
HGST Disk Drives w/AFC
Demos w/AFC

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Track Density and Linear Density

Track, Areal, Linear Density Perspective

Hard Disk Drive Products
Circles = Server products
Squares = Mobile products

Track Density, tracks/in
Areal Density CGR = 100%
Linear Density CGR = 30%

Areal Density, mbits/in²

Linear Density

100 kTPI (250 nm pitch)

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Track Pitch Challenge

Data track width: 250 nm

Data track width: 250 micrometer (human hair diameter x 3)
Minimizing Tracking Error

• The position error between magnetic head and data track on disk (called Track Mis-Registration-TMR) must be ~10% of track pitch.
  – For 250 nm track pitch, acceptable TMR is about 25 nm.

• Two factors affecting TMR:
  – Position Disturbance
  – Disturbance correction by close-loop control (servo)

• First-order TMR model:
  – TMR = Position Disturbance / Disturbance Correction by servo
Position Disturbance Sources

• **Majority of position disturbance is caused by air-flow induced by spinning disk.**
  - Example: 84 mm diameter disk spinning at 10,000 RPM
  - Linear speed at disk edge = 44 m/Sec ~~ 100 MPH!

• **Today’s disk drive has:**
  - Extremely high stiffness (Disk, Actuator).
  - Aerodynamically designed mechanical components.
  - Optimization such that the vibration node coincides with magnetic head location.
    - Example: Suspension beam

• **However, there is usually a limit on how well one can reduce this disturbance.**
  - Example: Disk can not be infinitely thick, mechanical tolerances.
Disturbance rejection by servo

- Disk drive has a close-loop control system (servo) that corrects position disturbance.
- Close-loop consists of:
  - Position error measured by head -> Controller generates input to voice-coil-motor (VCM) actuator -> Position error is corrected.
Servo Bandwidth

- Servo performance is measured by “servo bandwidth”.
  - Servo bandwidth is defined as the frequency where the open-loop gain crosses 0 dB line.
  - Higher bandwidth enables better disturbance correction.
  - Typical servo bandwidth of current HDD product is 1-1.5 kHz
  - Higher bandwidth is required for future HDDs.

\[
\text{Gain} = \frac{\text{Position}}{\text{Disturbance}} = \frac{1}{1+G(s)}
\]
Servo bandwidth limitation

- Servo bandwidth of current HDD is usually limited by mechanical resonances of head-positioning actuator (VCM, arm, and suspension).
Dual-Stage Actuator

• 1st Generation (Moving Suspension)
  – Prototyped by HTI, NHK, Magnecom, Fujitsu...
  – PZT controlled
  – Limitation by suspension dynamics

• 2nd Generation (Moving Slider)
  – TDK PZT based (fragile)
  – MEMS prototyping: IBM/Hitachi, Seagate...
  – Challenge for fabrication / assembly

• 3rd Generation (Moving Magnetic Head)
  – Concept phase: U-Tokyo/Hitachi...
  – Complicated integration of MEMS & magnetic
MEMS Microactuator Developed at Hitachi SJRC

- Rotary actuator
- Electrostatically driven
- Spring support (no friction)
- Stroke: ± 1 mm
- Actuator mass: 3-4 mg
- Plated nickel structure
- Output force: ~0.5 mN
Electrostatic Actuator

- Electrostatic force:
  \[ F = \frac{\varepsilon h V^2}{g} \times N \]
- To have large force output:
  - large \( h \)
  - small \( g \)
  - high \( V \)
  - More \( N \)
- Process capability limits aspect ratio (\( h/g \)).
- High-Aspect-Ratio process was developed.
High-Aspect Ratio Process

• High-Aspect Ratio (up to 20:1, or 40 um thick, 2 um wide)
• Metal (Nickel) Structure
• Process Steps:
  – Thick polymer coating
  – Highly directional oxygen plasma etching of polymer (electro-plating mold).
  – Nickel Electroplating.
Microactuator Design Example

- Push-Pull
- Three connections (Drive+, Drive-, GND or DC Bias)

2.1mm

Anchor to the substrate (Fixed)
Rotational Spring
Slider Binding Platform (Movable)
Electrostatic Actuator
Fabrication

- Mostly made by typical IC processes, such as photo-lithography, film deposition and etching.
- Some non-IC but magnetic head standard processes, such as electroplating
- Batch fabricated.
  - ~1500 chips from 4" wafer.
  - ~7000 chips from 8" wafer.
Process Steps (Cross Section)

- Insulator coating
- Metal Patterning
- Polymer Coating (40 um)
- High Aspect Ratio Polymer Etching (20:1)
- Thick nickel plating (40 um)
- Lithography and 2nd Ni plating
- Lithography and 3rd Ni plating/Au plating
- Polymer/resist removal
- Release
- Back-side lapping
Microactuator Chip Example
Example of finished wafer

~7000 Chips / wafer
Microactuator Assembly with slider and suspension

- Additional lead wire required:
  - Current 4 wires -> 7 wires
- Additional assembly step required:
  - Current two parts -> three parts
Microactuator assembly into drive

- Three extra wires
Microactuator Performance

• Frequency response (From input voltage to position)
  – Microactuator vs. conventional VCM actuator

![Graphs showing frequency response](image)

Microactuator Mass/spring mode. Damped by close-loop controller.
Servo Experiment

• Parallel design
  – Low frequency signal goes to VCM, and high frequency signal goes to microactuator.
Servo Experiment Results (1)

- Open-loop transfer function
  - 0 dB cross-over frequency (servo bandwidth) of 8 kHz by microactuator achieved, compare to ~1.8 kHz conventional VCM servo.
Servo Experiment Results (2)

- **Error rejection function**
  - With microactuator, error rejection is better up to 6 kHz.
Contact recording with microactuator

- Microactuator has small moving mass, thus more sensitive to any external force.

Off-track Disturbance by Contact Force

\[
\begin{array}{cccc}
  k_1 & c_1 & I_z_1 & k_2 & c_2 & I_z_2 \\
\end{array}
\]

Force Input: 0.7mN Normal Contact Force * 0.3 Friction Coefficient * Sin(15) Skew

VCM: Iz=4E-6 kg*m², fr=70, Q=5, L=50mm, Milli: Iz= 4.5E-9, fr=9kHz, Q=30, L=11, Micro: Iz=5.7E-13, fr=2kHz, Q=1, L=0.625mm
Other MEMS Application in Data Storage

Nanotechnology entering Data Storage

“MILLIPEDE”

Thermomechanical Read/Write on Thin Polymer Media

32 x 32 (1024) Cantilever Array Chip

Micromechanical x/y/z Scanner

40 nm pitch

40 nm bit size

=>most recent areal density demo

1Tbits/ inch² (single level)

Zurich Research Laboratory
Micro- and Nanomechanics Group

Courtesy of Dr. Peter Vettiger, IBM Zurich Lab
Conclusions

• Moving-slider microactuator for tracking servo was investigated.
• Microactuator was successfully fabricated and assembled into drive.
• Servo experiment was carried out, and 8 kHz servo bandwidth was demonstrated.
  – Conventional VCM has ~1.8 KHz bandwidth.
• Compatibility with contact recording needs to be investigated.

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