Reduce of windage effects in Hard Disk Drives by active damping control of suspensions

S.J.M. Cools & A.P. Teerhuis
master thesis, TU Eindhoven
advisor: R. A. de Callafon
Dynamics and Control Group
Dept. of MAE, UCSD
Windage

- Increase of rotational speed of HDD
- NRRO errors more dominant
Reduction of windage

- This can either be done passive or active
  - passive: re-design suspension or housing of drive
  - active: design of a feedback controller to add damping to resonance modes of suspensions

- In this project:
  - use of dual-stage actuator for active damping of suspension
Contents

- Models for dynamics of suspension and windage
- Methods of control
  - collocated
  - non-collocated
- Control design
- Results
- Continuing work
Models of dynamics & windage

Windage H
System G

G: dual stage actuator dynamics
H: spectral model of windage
Both 12\textsuperscript{th} order models
Methods of control

Non-collocated control

\[ (a) \]

- Controller
- Disturbance
- Input
- \( H_d \)
- \( G_d \)
- PES
Methods of control

Collocated control

Diagram showing a control system with a controller, disturbance input, and piezo output.
Methods of control (1)

Non-collocated control

- Direct measurement of windage disturbance
- Use both piezos for actuation
- Measuring relative head position
- Discrete time measurement of PES
Methods of control (2)

Collocated control

- Indirect measurement of windage disturbance
- Use one piezo for sensing and one piezo for actuation
- Continuous time measurement of piezo signal
- Continuous time control
Control design

- Create standard plant using knowledge of $G$, $H$ and control energy weighting $W_U$.
- Compute controller $C$ that minimizes transfer $d$: 
  $$\left\| \begin{array}{c}
  H \\
  \frac{C W_U}{1+GC} \\
  \frac{C W_U}{1+GC}
  \end{array} \right\|_2$$
Control design

- **NOTE:** windage effect $H$ changes to
  $$\frac{H}{1+GC}$$

- Both $G$ and $C$ help in reducing windage effect modeled in noise model $H$

- Controller computed via standard $H_2$/LQG solution

- Controller order (complexity) equals order of standard plant: $12^{th}$ order
Results: 12\textsuperscript{th} order controller

12\textsuperscript{th} order controller

\[ \frac{H}{1+GC} \]
Controller order reduction

- Reduce order to avoid implementation problems
  
  \[
  \text{minimize: } \frac{H}{1+GC} - \frac{H}{1+GC_{\text{RED}}} \|_2
  \]

  \[
  \rightarrow \left\| \frac{HG}{1+GC} \cdot \frac{1}{1+GC_{\text{RED}}} (C-C_{\text{RED}}) \right\|_2
  \]

  \[\text{weighting} \quad \text{difference}\]

- Minimize to find low order (3rd order) controller and iterate on weighting
  
  (initial guess: \(C_{\text{RED}}=C\))
Results: low order controller

- Reduced controller is 3\textsuperscript{rd} order controller

\begin{itemize}
  \item Reduced controller is 3\textsuperscript{rd} order
\end{itemize}
Results: windage reduction

Non-collocated control with 3rd order discrete controller reduces the effects of windage with 55%
Current research

- Exploring possibilities of collocated control strategy
  - Use one piezo for sensing and one for actuating
  - Find an experimental model of the suspension when flying over the HDD
  - Design a continuous time controller
  - Implement and test
Current research

- Results so far:
  - piezos can be used for sensing
  - measurements of suspension dynamics