Numerical investigation of the contact force in the head/disk interface

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Outline

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- Greenwood-Williamson contact model
- Hydrodynamic lubrication theory (Reynolds equation)

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- Inclusion of contact
- Results for steady state

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Introduction
Research goal

To increase storage density of hard disk drives

- flying height decreases (today: 5...20 nm)
- contacts are unavoidable
  (flying height in the range of surface roughness)
- additional force affects flying behavior

How to compute the contact force and include it into the air bearing simulator?
Greenwood-Williamson Model

Contact of two nominally flat surfaces

- How to model the topography of the surface?
  - rough surfaces as a collection of asperities
  - all asperity summits have the same radius
  - heights of asperities follow Gaussian distribution
  - no interaction between asperities

- Contacts are elastic → Hertz equations
Greenwood-Williamson Model

contact load $P$:

$$P = \frac{4}{3} \eta \tilde{A} E' \beta^{1/2} \sigma^{3/2} F_{3/2}(h)$$

$$F_{3/2} = \int_{h}^{\infty} (s - h)^{3/2} \Phi^*(s) ds$$

$$\Phi^*(s) = \frac{1}{\sqrt{2\pi}} e^{-\frac{s^2}{2}}$$

- $\eta$ - surface density of asperities
- $\tilde{A}$ - nominal contact area
- $E'$ - effective Young’s modulus
- $\sigma$ - heights in terms of standard deviation
- $F(h)$-scaled height distribution
- $h$ - standardized separation
- $s$ - standardized asperity height
- $\Phi(s)$-standardized height distribution (Gaussian)
Hydrodynamic Lubrication in a slider air bearing

Hydrodynamic bearing geometry:
$L >> h, u >> w$

Compressible Reynolds equation for gas bearings

\[ \nabla \cdot [ \bar{Q} p h^3 \nabla p ] = 6 \mu \mathbf{U} \cdot \nabla (p h) + 12 \mu \frac{\partial}{\partial t} (p h) \]

- $p$ = pressure
- $h$ = spacing
- $\mathbf{U}$ = velocity field
- $\mu$ = viscosity
- $t$ = time
- $Q$ = Poiseulle flow rate

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Slider equilibrium equations

\[
\begin{align*}
\left\{ 
\int \int_A [p(x,y) - p_a] \, dA - F_{z}^{ext} \\
\int \int_A [p(x,y) - p_a] (x - x_p) \, dA - M_{x}^{ext} \\
\int \int_A [p(x,y) - p_a] (y - y_p) \, dA - M_{y}^{ext}
\right\} =
\begin{bmatrix}
k_z & 0 & 0 \\
0 & k_\alpha & 0 \\
0 & 0 & k_\beta
\end{bmatrix}
\begin{bmatrix}
\frac{dh}{d\xi} \\
\frac{d\alpha}{d\xi} \\
\frac{d\beta}{d\xi}
\end{bmatrix}
\end{align*}
\]

in matrix notation:

\[
F^n - F_{ext} = K_s \, d\xi
\]
Research
Investigated slider types

Slider I
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Slider II

Level 1: closest to disk
Level 2: ~100nm recessed
Level 3: ~1µm recessed
Computing the contact force

Computation by the simulator
- compute area for each element from geometry
- spacing of each node \( \text{average} = \text{element spacing} \)
- compute contact force / pressure based on Greenwood Williamson contact model for each element

Approach was tested, seems reasonable

Add this force (pressure) to air bearing force (pressure)

Get new flying behavior
Computing the contact force

Equilibrium equation:

\[
\begin{align*}
\int_A \left[ p(x, y) - p_a \right] dA - F_{z ext} + F_{z contact} &= \int_A \left[ p(x, y) - p_a \right] (x - x_p) dA - M_{x ext} + M_{x contact} \\
\int_A \left[ p(x, y) - p_a \right] (y - y_p) dA - M_{y ext} + M_{y contact} &= \begin{bmatrix} k_z & 0 & 0 \\
0 & k_\alpha & 0 \\
0 & 0 & k_\beta \end{bmatrix} \begin{bmatrix} dh \\
d\alpha \\
d\beta \end{bmatrix}
\end{align*}
\]

where:

\[
F_{z contact} = \sum_{i=1}^{nel} F_{zi}^{contact}
\]

\[
M_{x contact} = \sum_{i=1}^{nel} M_{xi}^{contact}
\]

\[
M_{y contact} = \sum_{i=1}^{nel} M_{yi}^{contact}
\]

in matrix notation:

\[
F^n - F_{ext} + F_{contact} = K_s d\xi
\]
Results: Contact pressure
Variation of RPM, slider I

Asperity height: 10nm

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Variation of RPM, slider II

Asperity height: 10nm

Min. Flying height vs. RPM

Pitch angle vs. RPM

Roll angle vs. RPM

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Contact Force vs. Min. Flying Height

Asperity height: 10nm

Contact Force vs. Minimum Flying Height

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CMRR Center for Magnetic Recording Research
Variation of asperity height

Max. asperity height (sdsh):
- peak-to-valley
Summary

- Included contact force into steady state simulator
- No big influence on flying behavior for the investigated sliders
- Expected results verified:
  - velocity↑  ➔  contact force↓
  - min. flying height↑  ➔  contact force↓
Summary (contd.)

- Steady state is only of limited use
  - more interesting: dynamic case (load/ unload)

- better than other approaches
  - force & **moments** caused by contact
  - for each element
  - FEM-model, no special description/
    assumptions of geometry necessary
  - flying behavior effected
Future work

- Include contact force into dynamic simulator
- Contact force during loading and unloading
- Model validation