**BIFURCATION APPROACH TO THE ANALYSIS OF MULTIPLE FLYING HEIGHT STATES IN LOAD/UNLOAD HARD DISK DRIVE SYSTEMS**

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**ABSTRACT**

The application of numerical continuation methods to calculate suspension force-equilibrium position curve for hard disk drive sliders is proposed. The method efficiently detects multiple equilibrium positions. The relationship between suspension force offset and critical preload is found for the femto slider.

**INTRODUCTION**

Load/unload (L/UL) systems are often preferred to contact-start-stop (CSS) systems because they allow the slider-disk contact to be excluded. However, this technology brings new challenges to the design of the slider and suspension.

Multiple flying height states, that can be detected using static numerical analysis or by experiment [1], do not influence the performance of the CSS systems, where the slider never rises above several tens of nanometers. However, during the loading process an abrupt “jump” from the high flying height state to the nominal flying height state occurs and may result in data damage. Prediction of the critical suspension force corresponding to the “jump” is important for design of reliable load/unload systems.

In the present work, the appearance of additional equilibrium solutions is considered as a saddle-node (fold) bifurcation [2].

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**Numerical methods**

When the slider air-bearing surface configuration, disk rotation speed, radial position of slider, and skew angle are fixed, the air bearing force, $L$, pitching moment, $M_\theta$, and rolling moment, $M_\phi$, are functions of the slider position $u = (z, \phi, \theta)$. In the most simple suspension model, the air bearing force is balanced by the constant suspension force (preload), $W$, that is applied at offset $(x_s, y_s)$ from the slider center

\[
\begin{align*}
F_1 &= L(u) - W = 0 \\
F_2 &= M_\theta(u) - W x_s = 0 \\
F_3 &= M_\phi(u) - W y_s = 0
\end{align*}
\]

(1)

The existence and number of solutions of Eqn. (1) depends on the values of parameters $W, x_s$ and $y_s$.

Since the equilibrium position $u^0$ is found for some $W = W^0$, a solution branch can be continued in $(u, W)$ space. The Keller’s pseudo-arclength method [2] makes use of the following extended system:

\[
\begin{align*}
F(u^n, W^n) &= 0 \\
(u^n - u^{n-1})u^{n-1} + (W^n - W^{n-1})W^{n-1} - \Delta s &= 0
\end{align*}
\]

(2)

where $n = 1, 2, \ldots$ is the number of a point on the branch, $\Delta s$ expresses the length of the step and the dot denotes the derivative.
with respect to curve parameter $s$. The vector $(\hat{u}^0, W^0)$ must satisfy the relation $F_u \cdot \hat{u}^0 + F_W \cdot W^0 = 0$. Starting from the second step, the direction vectors are found from

$$
\begin{pmatrix}
F_u & F_W \\
\hat{u}^{n-1} & \hat{W}^{n-1}
\end{pmatrix}
\begin{pmatrix}
\hat{u}^n \\
\hat{W}^n
\end{pmatrix} = \begin{pmatrix} 0 \\ 1 \end{pmatrix}.
$$

(3)

In the fold point, the quantity $\psi = \det(F_u)$ has a simple zero. Therefore, the fold point can be located exactly by solving the following extended system:

$$
\begin{cases}
F(u, W) = 0 \\
\psi(u, W) = 0
\end{cases}
$$

(4)

The result can be directly extended to other offset values by the following iteration:

$$
\begin{cases}
F(u^n, W^n) = 0 \\
\psi(u^n, W^n) = 0 \\
(\hat{u}^n - \hat{u}^{n-1})\hat{u}^{n-1} + (W^n - W^{n-1})\hat{W}^{n-1} \\
+ (x^n_s - x^{n-1}_s)x^{n-1}_s - \Delta s = 0
\end{cases}
$$

(5)

The air film pressure is calculated using the finite element method. The nonlinear Eqns. (1, 2, 4, 5) are solved by using the modified Newton-Raphson method.

**Computational results**

Consider the femto slider with dimensions $0.88 \times 0.66$ mm. The recess depths of the base and shallow levels are $2,500$ nm and $300$ nm correspondingly (see Fig. 1). The disk rotation speed is $10,000$ rpm and the slider is positioned at the outer diameter, $45$ mm, with $16$° skew. The nominal flying height equals several nanometers.

**REFERENCES**
