Load/Unload 하드 디스크 드라이브 시스템에의 Fold Bifurcations 의 교란 유한요소 해석

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Perturbed Finite Element Analysis of Fold Bifurcations in Load/Unload Hard Disk Drive Systems

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ABSTRACT

The load/unload behavior of the hard disk drive slider is studied in terms of the air bearing static characteristics. The numerical continuation methods are applied to calculate suspension force – equilibrium position curve. The critical preloads of the femto size slider are analyzed. The bi-stability conditions are depicted on the skew angle – preload diagram. The perturbation method is used to check the stability of the solution branches.

1. Introduction

Load/unload (L/UL) systems are often preferred over contact-start-stop (CSS) systems because they allow the slider-disk contacts to be virtually eliminated.

Suk et. al [1] conducted theoretical and experimental research of multiple flying height states in L/UL systems. This phenomenon was not observed in the CSS systems where the slider never rises above several tens of nanometers. The existence of additional stable state depends on suspension preload and several other parameters. Prediction of the critical parameter values is important in designing reliable L/UL systems.

Hwang and Khan [2] considered the multiple flying height states from the viewpoint of the bifurcation theory. They applied the Keller's pseudo-arclength continuation method to build the equilibrium position – preload curves. The dynamic system eigenvalues were estimated in order to verify that the transition from single equilibrium to bi-stable condition is a saddle-node (fold) bifurcation [3].

In the present paper, the method described in [2] is applied to study the skew angle effect on critical preload. The finite element method is applied in the air pressure calculation.

2. Fundamental equations

The dynamics of translation, pitch and roll of the slider is governed by:

$$\mathbf{M}\mathbf{u}_{tt} = \mathbf{F}(\mathbf{u}, \mathbf{u}_t, W, \alpha \ldots), \quad (1)$$

where $\mathbf{M}$ is the slider inertia matrix, $u = (z, \phi, \theta)$ is the slider position vector and $\mathbf{F}$ is the total force, which depends on the slider position and several parameters, such as the suspension preload, W, the skew angle, α and other.

Consider perturbation from the equilibrium position, $u = \bar{u} + v(t)$ and substitute it into Eq. (1). We obtain the

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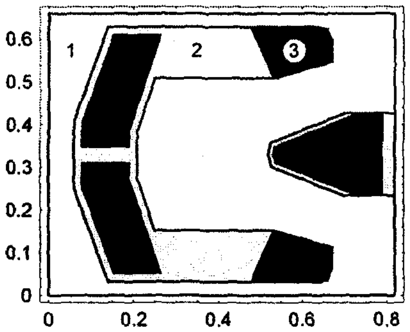

Fig. 3 The air-bearing surface of the femto slider.
1 – 2,500 nm recess level; 2 – 300 nm recess level; 3 – zero recess level

equilibrium condition and the linearized dynamic equation:

$$F(\bar{u},0,W)=0, \tag{3}$$

$$\mathbf{M}v_{tt} = \mathbf{F}_u v + \mathbf{F}_{u_t} v_t = -\mathbf{K}v - \mathbf{C}v_t, \tag{4}$$

where **K** and **C** are the air bearing stiffness and damping matrices. The eigenvalues of Eq. (4) define the stability of the equilibrium. Along the branch, there is a smooth one-one relationship between the equilibrium position and preload. The first point on the branch can be found by Newton-Raphson solution of Eq. (3). Starting from the second point, we make use of the extended system

$$\begin{aligned} &F(\bar{u}^n,0,W^n)=0, \\ &(\bar{u}^n-\bar{u}^{n-1})\dot{u}^{n-1}+(W^n-W^{n-1})\dot{W}^{n-1}-\Delta s=0, \end{aligned} \tag{5}$$

where Δs expresses the arclength between two consequent points along the solution branch and $(\dot{u}^{n-1},\dot{W}^{n-1})$ is the tangent vector, which can be found from the relationship

$$\dot{\mathbf{F}} = \mathbf{F}_u\dot{u} + \mathbf{F}_W\dot{W} = 0. \tag{6}$$

In the fold point, $\dot{W}=0$, and, thus, $\det \mathbf{F}_u = 0$ also. This condition together with Eq. (3) can be used to find the critical preload for any given skew angle.

3. Calculation results

Consider the femto slider (Fig. 1). The air bearing surface has 18 nm crown and 2 nm cross-crown. The disk rotation speed is 10,000 rpm and the slider is positioned at the outer diameter, 45 mm. The preload is applied with offset 0.1 mm from the slider center toward the trailing edge.

Figure 2 shows solution branches for two different skew angles. The highest branch is the High Flying Height State (HFHS). In the fold point, it turns to the

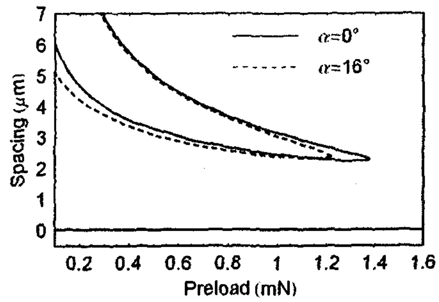

Fig. 2 Preload-spacing diagram

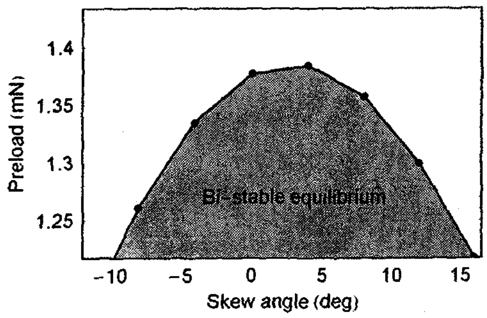

Fig. 1 Stability diagram

unstable middle branch. The lowest branch corresponds to the Nominal Flying Height State (NFHS). During loading, the transition from HFHS to NFHS can be expected at critical spacing equal 2.5 μm and critical preload equal 1.2 mN and 1.3 mN for 0° and 16° skew respectively.

In Figure 3, we can see how the critical preload changes with skew angle.

4. Conclusions

The loading characteristics of the femto slider were studied by using the numerical continuation method. It is found that the critical preload has maximum at skew angle about 3 degree.

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