Dynamic Analysis of Sliders in Optical Memory System

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Identification method is formulated to evaluate the dynamic characteristics of air bearings under NFR (Near Field Recording) sliders. Using dynamic analysis, impulse responses and frequency response functions of NFR sliders are obtained on numerical non-linear models including rigid motion of slider and fluid motion of air bearing under the slider. System parameters are identified by modal analysis method and instrumental variable method. The identified system parameters of sliders are utilized to evaluate the dynamic characteristics of air bearings.

1. Introduction

Storage devices with large capacity have been recently required to satisfy the increment of information data in HD-TV, 3D graphic, etc. In accordance with this tendency, the associated studies have been performed intensively to develop sub-storage devices with high density, such as HDD, ODD etc. [1,2]

The study on Near Field Recording drives (NFR) has progressed recently, which can conduct optical recording with high density. NFR method is characterized by combination method of conventional optical disk drives and hard disk drives(HDD), where the slider with optical lens floats on optical disk with small flying height. Slider-air bearing system consists of a suspension system which sustains the slider, and a non-linear characterized air bearing which has a thin lubricant film between the slider and the optical disk. The flying height of the NFR slider is relatively higher than HDD sliders. However, it is inevitable to take an increase of slider mass because of attachment of the lens. Thus, it is important to evaluate dynamic characteristics for the design of a NFR slider which may be sensitive for disk bump, etc. The identification of system parameters is required to evaluate the dynamic characteristic.

Allyn[3] suggested various identification methods at the simple systems and K.M. Lee[4] used high order frequency response function method. Shi[5] identified a coupled system of non-linear rubber using experimental data and matrix-exponential method. Bogy[6~9] identified the system parameters of sliders in HDD using modal analysis method. Y.B. Lee[10] identified the system parameters of rotor system from the measured frequency response function using least square method and instrumental variable method.

In this study, impulse response functions are obtained on the non-linear air bearing to extract system parameters of a NFR slider system. In addition, this study identifies natural frequencies and mode shapes from the frequency response functions using impulse response functions and evaluates system parametric matrices such as mass, damping and stiffness matrices. On the identification process, the least square method and the instrumental variable method are used to improve the accuracy of results.

2. System Modelling and Identification Method

2.1 Governing equations of a slider system

Assuming the slider is a rigid body and the air bearing under the slider is steady state within small range. The slider-air bearing system can be modeled as Fig. 1.

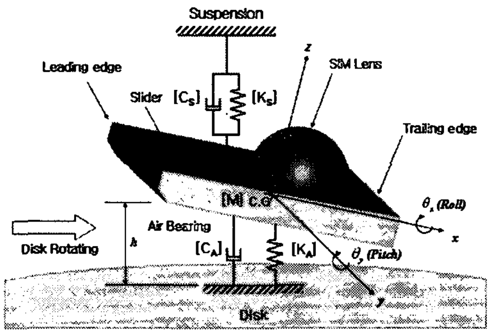


Fig. 1 Mathematical model of a NFR slider

The Governing equations of the slider motion are written as [8]

$$m\frac{d^2z}{dt^2}+c_z\frac{dz}{dt}+k_z z=f_z(t)+\iint_A (p-p_s)dA \tag{1}$$

$$I_{\theta_y}\frac{d^2\theta_y}{dt^2}+c_{\theta_y}\frac{d\theta_y}{dt}+k_{\theta_y}\theta_y=f_{\theta_y}(t)-\iint_A (p-p_s)xdA \tag{2}$$

$$I_{\theta_x}\frac{d^2\theta_x}{dt^2}+c_{\theta_x}\frac{d\theta_x}{dt}+k_{\theta_x}\theta_x=f_{\theta_x}(t)+\iint_A (p-p_s)ydA \tag{3}$$

And generalized Reynolds equation in air bearing analysis of ultra thin lubricant films is written as[8]

$$\frac{\partial}{\partial x}(ph^3Q\frac{\partial p}{\partial x})+\frac{\partial}{\partial y}(ph^3Q\frac{\partial p}{\partial y})=6\mu V_x\frac{\partial(ph)}{\partial x}+6\mu V_y\frac{\partial(ph)}{\partial y}+12\mu\frac{\partial(ph)}{\partial t} \tag{4}$$

2.2 Analysis method

The equations of motion (1) ~ (3) are associated with generalized Reynolds non-linear equation (4) in same time step. So we can obtain dynamic motion of slider system by numerical analysis using the finite differential method.

Assuming the above system is steady, linear and time-invariant system within small range, it can be written as

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=\{f(t)\},\ u=[z,\theta_y,\theta_x]^T \quad (5)$$

Considering an impulse input, external force of equation (5) can be expressed as

$$\{f(t)\}=[M][\dot{z},\dot{\theta}_y,\dot{\theta}_x]^T\delta(t) \quad (6)$$

For each input to the mass center of 3 DOF, the impulse and steady state responses are obtained. The analytical frequency response functions are obtained by performing the Fourier transformations.

2.3 Identification method for system parameters

Equation (5) is rewritten in state space as

$$[A]\{\dot{y}\}+[B]\{y\}=\{q(t)\} \quad (7)$$

$$\text{where } [A]=\begin{bmatrix} C & M \\ M & 0 \end{bmatrix}_{6\times6},[B]=\begin{bmatrix} K & 0 \\ 0 & -M \end{bmatrix}_{6\times6} \quad (8)$$

$$\{y\}=\begin{Bmatrix} u \\ \dot{u} \end{Bmatrix}_{6\times1},\{q(t)\}=\begin{Bmatrix} f(t) \\ 0 \end{Bmatrix}_{6\times1} \quad (9)$$

The frequency response function for the response at each DOF k due to the excitation at DOF l is

$$H_{kl}(i\omega)=\sum_{j=1}^{3}\left[\frac{A_{klj}}{(i\omega-s_j)}+\frac{A^*_{klj}}{(i\omega-s^*_j)}\right] \quad (10)$$

$$s_j=-2\pi\zeta_j f_j+i2\pi\sqrt{1-\zeta_j^2}\,f_j \quad (11)$$

where f_j and ζ_j are the modal frequency and damping ratio of j-th mode ,respectively.

The modal frequencies are estimated by single mode curve fitting over the specified frequency band of each analytical FRF. And the mode shapes can be obtained from equation (10). The system parameter matrices *[M], [C], [K]* can be obtained from equation (7) with the estimated modal parameters.

The estimated system parameters are relatively accurate, but the parameters probably have few error due to the non-linear characteristic of FRF, measurement error and procedure of curve fitting. So, least square method and instrumental variable method are used to improve the accuracy of system parameters.

The equation of the rigid body motion is written as

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=\{f(t)\} \qquad (12)$$

Assuming the solution of equation (12) as

$$u(t)=Ue^{i\omega t},\ f(t)=Fe^{i\omega t} \qquad (13)$$

Equation (12) can be rewritten as

$$\left[[K]-\omega^2[M]+i\omega[C]\right]\{U\}=\{F\} \qquad (14)$$

Thus the frequency response function is

$$[H_E(\omega)]=\left[[K]-\omega^2[M]+i\omega[C]\right]^{-1} \qquad (15)$$

with

$$[H_E(\omega)]\left[[K]-\omega^2[M]+i\omega[C]\right]=[E]+[S] \qquad (16)$$

where

$[H_E(\omega)]$: Experimental FRFs

$[E]$: Identity matrix

$[S]$: Noise matrix

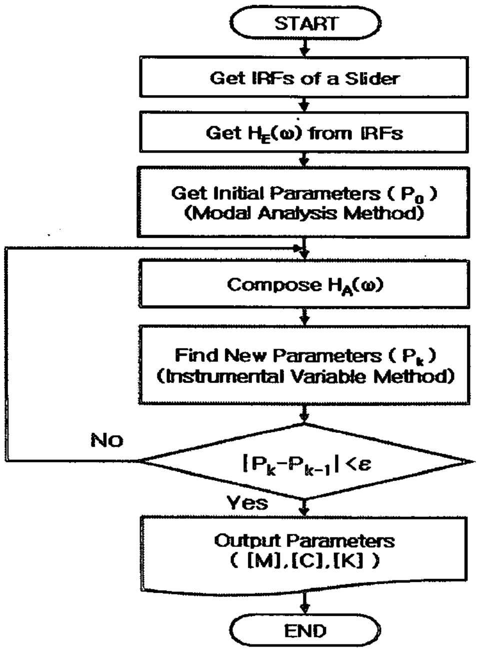


Fig. 2 Flow chart

Multiplying equation (15) by $[H_A(\omega)]^T$, we obtain

$$[H_A(\omega)]^T[H_E(\omega)]\left[[K]-\omega^2[M]+i\omega[C]\right]=[H_A(\omega)]^T\left([E]+[S]\right) \qquad (17)$$

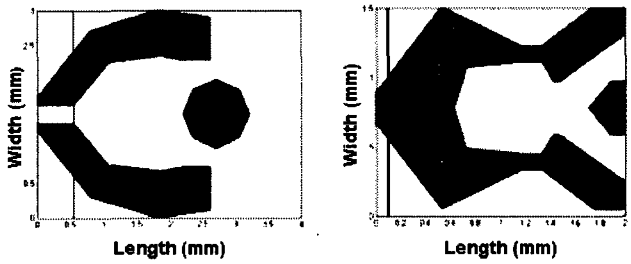
where

$[H_A(\omega)]$: Analytical FRFs

The initial $[H_A(\omega)]$ are composed of the system parameters from the modal analysis method. And equation (17) with new FRFs can give new parameters. The procedures are iterated until satisfying convergence conditions of parameters.

3. Application

The modal analysis method and the instrumental variable method are applied to extract the system parameters of the dynamic characteristics of NFR sliders. For comparing dynamic characteristics, the same procedure is applied for extracting the parameters of *NutCracker* slider being the standard slider of HDD.



(a) NFR *(b) HDD*

Fig. 3 Rail shape of sliders

Table 1 Conditions of sliders

Conditions	Values	
	NFR	HDD
Disk speed (rpm)	2400	5400
Radial position (mm)	45	25
Initial height (nm)	110	31
Skew angle (degree)	0	0
Pre-load (gram)	5	3.5
Flying height (nm)	107.5	33.0

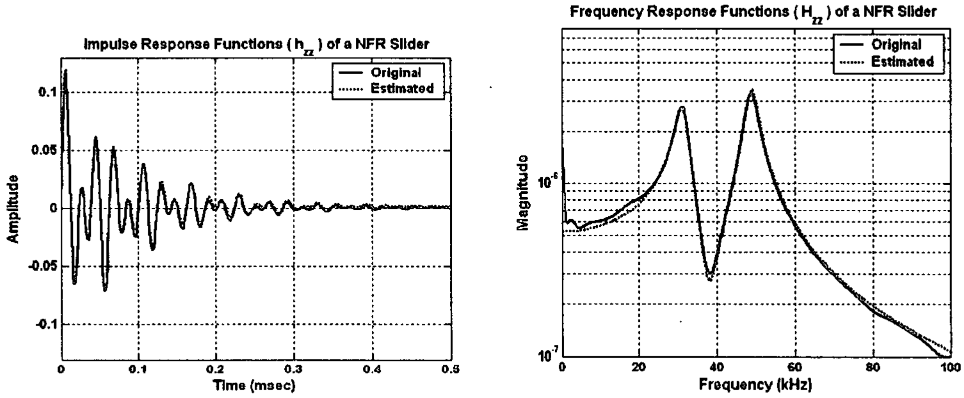
The mass matrix for each slider is obtained from the geometry and the density of the material.

$$M_{e(NFR)} = \begin{bmatrix} 3.000\times10^{-5} & 0 & 0 \\ 0 & 3.809\times10^{-11} & 0 \\ 0 & 0 & 2.144\times10^{-11} \end{bmatrix} (kg, m) \quad M_{e(HDD)} = \begin{bmatrix} 5.952\times10^{-6} & 0 & 0 \\ 0 & 2.176\times10^{-12} & 0 \\ 0 & 0 & 1.361\times10^{-12} \end{bmatrix} (kg, m)$$

Fig. 3 and Table 1 show the rail shapes and the analysis conditions, respectively. Fig. 4 shows IRF($[h_E(\omega)]_{zz}$) and FRF($[H_E(\omega)]_{zz}$) at the mass center of a NFR slider from original model, and also shows IRF and FRF from model based on the estimated system parameters. It shows indirectly that the estimated system parameters are close to the original values.

Table 2, 3 show modal parameters and system parameters of the slider air bearing systems, respectively.

It shows that there is little difference between the results of HDD slider and reference data[7] in identifying system parameters. The NFR slider has large stiffness due to the large rail shape. However, since the NFR slider has the larger mass and small squeeze effect[7] caused by large flying height, natural frequencies are lower than those of the HDD slider. However, because the rotating speed of a NFR drive may generally become lower due to high recording density, it is predicted that the low natural frequencies of the NFR slider may not become severe problem in controlling slider height. And damping ratio is relatively large in low frequencies comparing with that of the HDD slider. Thus it is expected that the designed rail shape of NFR slider is good for a bump, compared with dynamic characteristics of commercial HDD slider.



(a) Impulse response functions (h_{zz}) (b) Frequency response functions (H_{zz})

Fig. 4 Original functions and estimated functions

Table 2 Natural frequencies and modal damping ratios of sliders

Mode	NFR		HDD (*NutCracker*)	
	f_n (kHz)	ζ (%)	f_n (kHz)	ζ (%)
1	31.4	5.35	58.6	4.64
2	49.1	3.49	76.8	5.01
3	76.9	2.87	106.7	4.28

Table 3 Estimated system parameters of sliders

NFR	3.02e-05	5.60e-08	-7.89e-11	5.70e-01	1.54e-03	1.05e-04	2.83e+06	5.55e+03	-2.24e+01
	4.52e-10	3.84e-11	3.33e-15	2.53e-05	9.44e-07	1.09e-08	3.60e+02	2.19e+00	-6.83e-03
	2.25e-13	-2.28e-15	2.22e-11	-3.06e-06	-5.57e-09	6.15e-07	-9.08e+00	-2.40e-02	5.18e+00
HDD (*NutCracker*)	5.96e-06	5.61e-09	6.94e-12	2.68e-01	2.34e-04	-1.60e-05	1.55e+06	8.79e+02	9.09e+00
	-5.33e-11	2.26e-12	-8.28e-15	-7.09e-05	4.16e-08	1.49e-08	-5.78e+02	2.15e-01	-8.00e-03
	-1.41e-13	-2.44e-15	1.38e-12	-3.68e-07	2.68e-10	6.64e-08	7.07e+00	-7.28e-04	3.22e-01

4. Conclusions

Dynamic analysis and identification method are formulated to evaluate the dynamic characteristics of air bearings under NFR (Near Field Recording) sliders. The linear system is modeled within small range in order to gain the quantitative system parameters of the NFR slider air-bearing system that has a large non-linearity. After using the modal analysis method, least square method and instrumental variable method are applied to eliminate error due to non-linear characteristic and measurement noise.

Acknowledgement

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