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모달 튜닝을 이용한 하드디스크 구동기의 모델 개선

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Model Updating of Head Stack Assembly using Modal Tuning

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요약

하드디스크의 트랙 밀도를 높이기 위해서는 충분한 서보대역을 갖는 액츄에이터를 개발하는 것이 필수적이다. 이 논문에서는 액츄에이터의 동특성 중에서 서보대역을 제한하는 주된 요인을 알아보기 위해 실험 모드 해석과 유한 요소 해석을 수행하였다. 우선 액츄에이터를 구성하고 있는 VCM 코일, E 블럭, 서스펜션등의 부분계에 대한 유한 요소 해석을 수행하였고 모달 실험을 통해 이를 검증하였다. 검증된 각 부분계의 모델을 결합하여 한 개의 서스펜션을 갖는 액츄에이터 시스템의 유한 요소 모델을 개발하였고 이를 통해 서보 성능과 관계된 모달 파라미터들을 규명하였다.

1. Introduction

The areal recording density has increased very rapidly since 1990 and Appearance of HDD with recording density of 10 GB/in^2 is expected. This is projected to place extreme requirements on the precision with which the head actuator rapidly moves the read/write heads across the disk surfaces and maintains them over the specific data tracks for reading and writing information. It is therefore required to improve further the read/write head positioning servo performance for future high track density hard disk drives. It is known that the positioning accuracy of the read/write heads strongly depends on the servo bandwidth which is limited mainly by inherent mechanical resonance of the head actuator assembly.

It is common feature of present hard disk drives that a strong system vibration mode exists between 3 and 5kHz, which involves the coupled vibration of the head, suspensions, arms and a ball bearing assembly. The system mode, which is generated by the distortion of the ball bearing, is particularly troublesome for the servo system since it is very sensitive to the assembly process and contributes to significant off-track error. [1][2][3]

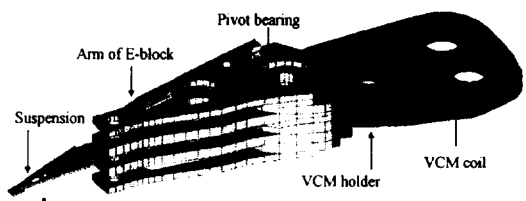

Fig. 1 Schematic of head stack assembly used in test

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In this paper, FE model verified by experiment is developed and the modal parameters related to servo performance are identified. Going a step forward, it is obtained the basic technology to develop the new head actuator assembly.

2 . FE modeling of E-block components

The HDD Actuator system is made up of sub-components which are VCM coil, VCM holder, actuator arm and suspensions. To develope more accurate FE model of that complex structure, first of all, FE models of each component are constructed. Nastran for windows is used as FEM solver.

2.1 FE modeling of coil

The FRF(Frequency Response Function) for VCM coil is measured on a soft sponge for a vertical direction and a horizontal direction. The coil is exited by an impact hammer and velocity is measured by LDV(Laser Doppler Vibrometer). Modal parameters are estimated by SMS Star-Modal.

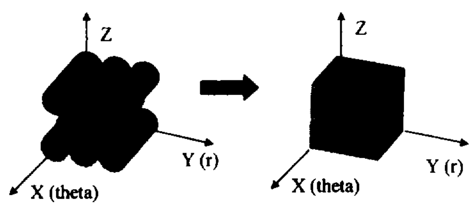

Fig. 2 Modeling of coil

Real VCM coil is piled up with fine coil. but generally it is modeled as solid element as shown in Fig. 2. So the element must have an anisotropic property. Accordingly local coordinates are introduced partly and longitudinal stiffness should be larger than lateral that. Because of the VCM coil's property, there is more or less errors between dynamics of its FE model and that of actual model.[2] And FE model is modeled differently, compared with actual model due to complexity of connection part with E-block. Consequently, corners of coil have different stiffness from otners. Coefficients used in analysis are referred from the value of reference papers and tuned by experimental data.

Table 1 Natural frequencies of a coil

Mode #	EMA(Hz)	FEA(Hz)	error (%)
1 (Z)	1660	1659	0
2 (Y)	3020	2886	4
3 (Z)	3550	3006	15
4 (Y)	4570	4944	8
5 (Z)	7200	5667	21
6 (Z)	7610	6519	14
7 (Y)	9470	8977	5

2.2 FE modeling of a VCM part

The experiment of VCM part is performed to 12 measurement points of vertical direction. Because of coil's natural frequencies error, VCM part also has some error of natural frequencies between FE model and actual model. In addition to, a holder part is the composit material which has different properties according to molding conditions. The poisson's ratio is assumed like that of general metal and young's modulus of maker's data is introduced as the initial value and tuned by experimental data.

Table 2 Natural frequencies of a VCM part

Mode #	EMA(Hz)	FEA(Hz)	error (%)
1	2330	2468	5
2	3330	3057	8
3	4380	-	-
4	5860	5609	4
5	7600	6500	14

2.3 FE modeling of a arm part

The experiment of an arm part is performed to 38 measurement points for vertical direction. A result about an arm part which consists of aluminum shows good agreement between FE model and actual model.

Table 3 Natural frequencies of a arm part

Mode #	EMA(Hz)	FEA(Hz)	error (%)
1	1760	1780	1
2	2000	1970	2
3	4560	4234	7
4	8320	8907	7
5	8610	9240	7
6	10300	10804	5
7	10670	10987	3

2.4 FE modeling of a E-block

The FRF for E-block is measured on a soft sponge for 57 points of vertical direction and 20 points of horizontal direction. A sponge is sufficiently soft, so the rigid mode frequency of the E-block is very lower than the first local mode of that. For a vertical direction, lower arms are measured in tilted state. Error of natural frequencies between FE model and actual model is less than 8%. It can be resonable for complex structures like E-block. The third mode of FE model is not founded from the result of experiments. For the second mode of experiment includes both the second and the third modes of a FE model. In order to analyze accurately, the result of MAC (Measurement Assurance Criteria) test is presented. The lateral bending mode that can make tracking error is generated at near 8000 Hz.

Table 5 Natural frequencies of a arm part

#	EMA(Hz)	FEA(Hz)	error (%)	Mode shape
1	1180	1137	4	E_block 1st bending
2	1810	1780	2	Arm bending
3	-	1820	-	E_block 1st torsion
4	2020	1965	3	Arm bending
5	2720	2659	2	Arm bending
6	3650	3466	5	E_block 2nd bending
7	4850	4527	7	Arm bending + VCM torsion
8	6230	5850	6	VCM torsion
9	7710	8315	8	E_block lateral bending
10	-	7458	-	VCM torsion
11	8570	8905	4	Arm torsion
12	8790	9197	5	Arm torsion

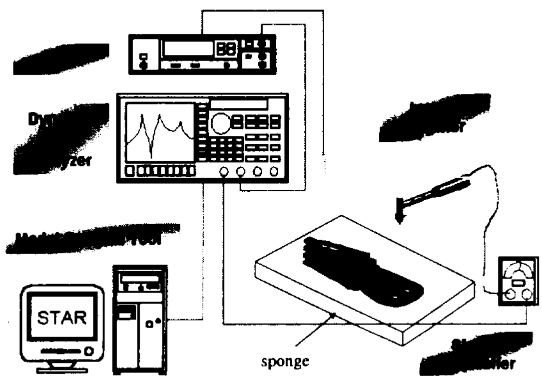

Fig. 3 Experimental installation

Table 4 Material properties used in a E-block model

	E (mN/mm^2)		ρ (Kg/mm^3)	ν
Arm part (aluminum)	60*E6		2.56*E-6	0.4
VCM holder (vectra A130)	12*E6		1.62*E-6	0.4
Coil (copper piled)	$E_x(E_\theta)$	30*E6	4.9E-6	0.3
	$E_y(E_r)$	3.8*E6		
	E_z	3.0*E6		
	$E_x(E_\theta)^*$	2.5*E6		
	$E_y(E_r)^*$	3.0*E6		
	E_z^*	3.0*E6		

* coil's property at left corners

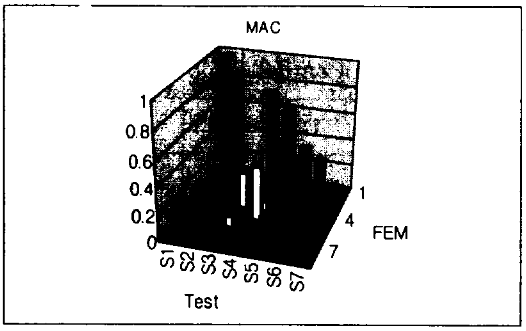

Fig. 4 MAC of E-block

3 . FE modeling of a suspension

The suspension system, in other word, HGA(Head Gimbal Assembly) consists of load beam, flexure, slider and base plate. The load beam is fixed on a base plate by seven welded points. A base plate is mounted to an actuator arm. The schema of an experiment is suggested to the Fig. 5. The suspension is exited by a shaker. FRF is measured by PSV(Polytec Scanning Vibrometer) from 0Hz to 8kHz. [4]

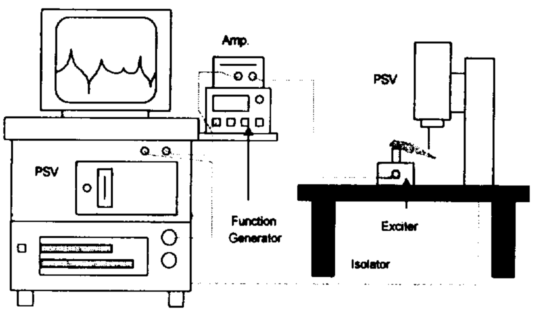

Fig. 5 Experimental setup of a suspension

A finite element model of the suspension is made up of 772 elements and 1028 nodes. The base plate, the suspension and the flexture is assembled by coupling nodes around welded points. But just coupling nodes is not enough to represent constraint force. The multi-point constraint to remove vertical translation around welded points is applied. The result shows a good agreement. Particularly, the natural frequencies of modes such as torsion, sway generating tracking errors have error within 7%. The slider rolling mode and the slider pitching mode of the flexture show large error due to modeling inaccuracy. So FE model is tuned by the sensitivity analysis method. Four design parameters of local thicknesses are shown in Fig. 6. [5][6]

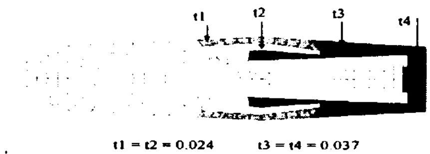

Fig. 6 Design parameters of a flexture

Table 6 Material properties used in a model

Component	load beam	flexure	base plate	slider
Material	stainless steel	stainless steel	stainless steel	ceramic
E (GPa)	193	193	193	412
ρ(kg/m^3)	7500	7500	7500	4300
ν	0.3	0.3	0.3	0.27
t (mm)	0.076	0.0305	-	$2\times1.6\times0.43$

* hatched area thickness : 0.036 mm

Table 7 Natural frequencies of a suspension

	EMA	FEA	error (%)	mode shape
1	171	179	4.7	1st bending
2	1166	1186	1.7	slider rolling
3	1416	1424	0.6	slider pitching
4	2675	2739	2.4	1st torsion
5	3053	2760	9.6	2nd bending
6	5885	5489	6.7	sway
7	7219	7332	1.6	3rd bending
8	7804	8261	5.8	2nd torsion

4. FE modeling of the Head Stack Assembly

In FE model, the pivot bearing is modeled by a steel shaft and linear spring elements. An inner face of shaft is fixed in all degrees of freedom. The top of the shaft is free to simulate the test condition without cover. Total thirty two spring elements are used. One end of axial spring is connected shaft and the other end of it is fixed. The stiffness of springs is 750000(mN/mm) to the radial direction and 550000(mN/mm) to the axial direction. These values are referred from references [2][6] and tuned by experimental results. The tested actuator has only one suspension without a dummy mass and the finite element model consists of 3782 nodes and 2156 elements. The verified suspension is assembled to a arm of E-block by coupling nodes. Measurement points are the same as those of E-block at free boundary condition and this E-block is assembled to pivot mounted to zig. An appropriate point are exited by an impact hammer and other 72 points including it are measured to the z-axis by LDV. An additional modal test is peformed to the lateral direction to measure lateral modes. Finally, modal parameters are estimated by the Star-Modal

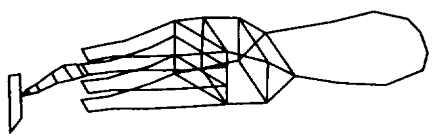

Fig. 7 Slider rolling (EMA)

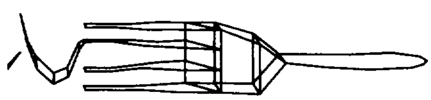

Fig. 8 Suspension 2nd bending(EMA)

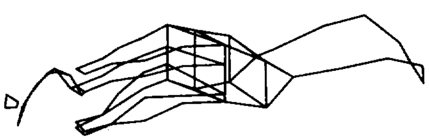

Fig. 9 E-block 3rd bending (EMA)

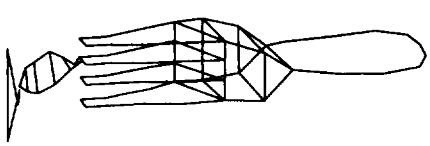

Fig. 10 Suspension sway (EMA)

It can be seen that rocking mode(567Hz) and lateral translation mode(3656Hz) are strongly related to bearing stiffness. The lateral translation mode and the suspension sway mode produce the residual vibration in settling operation and limit the servo bandwidth. The error between the result of FEA(finite element analysis) and that of EMA(experiment modal analysis) is mostly less than 10% except a suspension second torsion mode. So the result is resonable to complex structure.

Table 8 Natural frequencies of the Head Stack Assembly

	EMA (Hz)	FEA (Hz)	Mode shape	error (%)
1	165	175	suspension 1st bending	6.1
2	567	604	rocking (mostly VCM bending)	6.5
3	1150	1185	slider rolling	3.0
4	1310	1387	VCM torsion	5.7
5	1420	1420	slider pitching	0
6	1630	1453	1,2,3,4, arm bending +VCM torsion	11
7	1850	1780	1,4 arm bending (out of phase)	3.8
8	2000	1871	1,4 arm bending (in phase)	6.5
9	2440	2576	suspension 1st torsion	5.6
10	2590	2381	1,2,3,4 arm bending	8.1
11	3070	2863	suspension 2nd bending	6.7
12	3300	3305	E-block 2nd bending	0
13	3656	3473	lateral translation	5.0
14	3720	3880	E-block 1st torsion	4.3
15	-	4026	longitudinal translation	-
16	4300	4737	E-block 3rd bending	10
17	5510	5196	suspension sway	5.7
18	5710	5967	E-block bending +VCM torsion	4.5
19	6570	6026	E-block 2nd torsion	8.3
20	7100	8019	suspension 2nd torsion	13

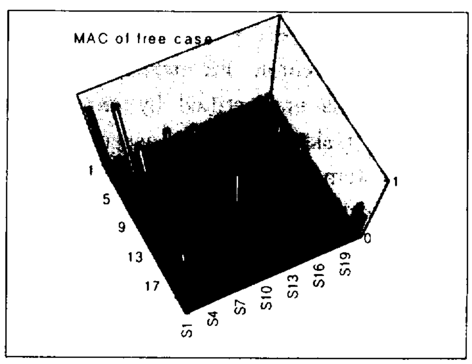

Fig. 11 MAC of HSA

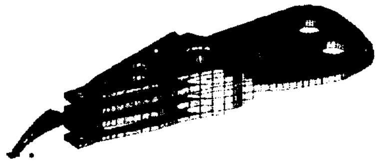

Fig. 12 Suspension 2nd bending (FEA)

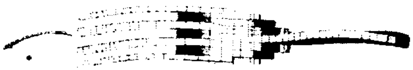

Fig. 13 E-block 3rd bending (FEA)

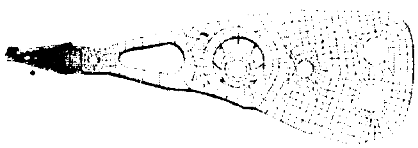

Fig. 14 Lateral translation (FEA)

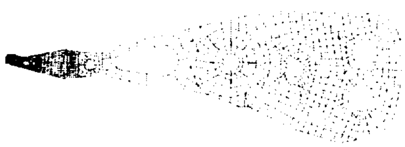

Fig. 15 Suspension sway (FEA)

5. Conclusion

In this paper, the dynamic characteristics of the HDD actuator system which are main obstacles confining servo bandwidth are investigated by analytical and experimental modal analysis. To develop more accurate FE model, FE models of sub-components are verified by experiment and combined to make head stack assembly(or HDD actuator system). Coil was modeled as the soild element which has different stiffness according to the direction for its anisotropic property. In case of the suspension, The slider rolling mode and the slider pitching mode of the flexture show quite large error due to inaccurate modeling. So the FE model is tuned by sensitivity anaiysis method with design parameters of 4 local thicknesses. The suspension sway mode that a head is off from the center line of the suspension can generate off-track error. Because bearings are not rigid, the stiffness of ball bearings affects the natural frequencies of the vertical rocking mode and the lateral translation mode.

Afterward, dynamic characteristics of HSA will be analyzed at operating condition considered preload and air-bearing effect.

6. Acknowledgement

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7. Reference

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