정보저장기기 서스펜션의 동특성 해석 및 최적설계
Dynamic Analysis and Optimum Design of Suspensions for Information Storage Devices

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Key Words : Size Optimization(치수 최적화), Suspension(서스펜션), Sway Mode(스웨이 모드) Finite Element Analysis(유한 요소해석).

ABSTRACT

The suspension is a structure that supports reading, writing head in information storage device. In order to develop the information storage device of high track density, it is necessary to study about the suspension. To satisfy operation condition of information storage device, the suspension shape is very important since it correlates to dynamic characteristics. Therefore, it is necessary to analyze the dynamic characteristics by using finite element analysis and to optimize the suspension of information storage device using size optimization and topology optimization. The suspension has various modes according to different kinds of frequency bandwidth. Sway mode and second torsion mode are especially critical among them. In this paper, we investigated method to improve bandwidth of sway and second torsion mode of HDD and ODD suspension by using size optimization and topology optimization.

1. Introduction

Information storage devices have been used in from personal computers to super computers to record information of various capacities. Capacity capability of information storage device is determined by data quantity per unit area and technical problems must be solved to improve it. The problem is that bandwidth of servo system consists of suspension, slider, VCM (Voice Coil Motor), actuator arm etc is limited in about 800Hz.(1) Hence, bandwidth of servo system is confined by the suspension of information storage device having low resonant frequency. Therefore, improvement of information storage device performance, and especially development of disk drive having high track density is retarded.(2) Data is processed by reading and writing head. Tracking error could occur due to head vibration which hinders the improvement of memory integration. Suspension is a structure that supports reading and writing head in information storage device. In order to develop the information storage device of high track density, it is necessary to study about the suspension .(3)(4) To satisfy operation condition in information storage device, the suspension shape is very important since it correlates to dynamic characteristics. Therefore, it is necessary to analyze the dynamic characteristics by using FEA(Finite Element Analysis) and to optimize the suspension of information storage device using size optimization, and topology optimization.(5) Nowadays, rotary type actuator which is highly reliable and light weighted is used to improve the access time compared to linear type actuator and to reduce the size of information storage device. But rotary type actuators operate on wide direction and therefore their stiffness reduces. Rotary type actuator has a truss structure and is widely designed to raise stiffness and to reduce rotation inertia about wide direction. Rotary type actuator is weakened structurally by torsion and sway mode.(6) The suspension has various modes according to different kinds of frequency bandwidth. Sway mode and second torsion mode are especially critical among them. Sway mode of the suspension causes both torsion mode and lateral translation mode and therefore head of slider slips out of the centerline of the suspension. In this paper, we investigated method to improve bandwidth of sway,

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second torsion mode of HDD(Hard Disk Drive), ODD(Optical Disk Drive) suspension by using size optimization, topology optimization. Commercial software GENESIS is used for the investigation.

2. Optimization of HDD suspension

2.1 Shape of HDD suspension

In this study, we used Type 850 head gimbal assembly made by Hutchinson technology. It is composed of suspension, flexure, slider, and base plate as shown in Fig. 1. Generally, load beams with flexure are called suspension, but occasionally load only beams without flexure are also called suspension. Suspension is designed to give degree of freedom of normal direction motion and to protect vibration of lateral direction. Flexure is very flexible structure locates between load beam and slider to give degree of freedom on pitch and roll motion.[1] Material properties and constants of the suspension are shown in Table 1.

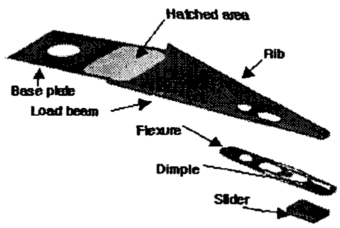

Fig. 1 Schematic of the type 850 suspension assembly

Table 1 Material properties and constants of the suspension[7]

Component	Material	E(GPa)	ρ(kg/m³)	ν	t(mm)
Load beam	Stainless Steel	193	7500	0.3	0.076
Flexure	Stainless Steel	193	7500	0.3	0.0305
Hatched area	Stainless Steel	193	7500	0.3	0.034
Slider	Ceramic	412	4300	0.27	2*1.6*0.43

Table 2 Natural frequencies of the suspension[7]

	Mode	Exp(Hz)	FEA(Hz)	Error (%)
1	1st Bending	171	179	4.7
2	Slider Rolling	1166	1261	8.1
3	Slider Pitching	1416	1301	8.1
4	1st Torsion	2675	2449	8.4
5	2nd Bending	3053	2776	9.1
6	**2nd Torsion (1) (sway)**	5885	6030	2.5
7	3rd Bending	7219	7348	1.8
8	**2nd Torsion (2) (real)**	7804	8014	2.7
9	2nd Torsion (3) (local)	9391	9232	1.7
10	Flexure mode	11500	10649	7.4

2.2 Finite element modeling of HDD suspension

FEA has been used to analyze dynamic characteristics of suspension for free load by using GENESIS. A finite element model of suspension is composed of 9847 elements and 10975 nodes. The suspension and the flexure are assembled by coupling nodes around weld points. Dimple points are just used to constrain normal direction motion of suspension.

2.3 FEA of HDD suspension and verification

The calculated modal frequencies of the main modes are very close to the experimental result as shown Table 2. Mode shapes of the suspension are shown in Fig. 2. Difference of natural frequency between developed finite element model and experiment result error is within about 10 %. Even though mode 6 is a local mode as shown in Lee' experiment result, but by the definition of sway mode, which means both torsion occurring and lateral translation mode with slipping head of slider, it is reasonable to use this mode as sway mode in this case. Accordingly, in this study, mode 6 is assumed as sway mode.

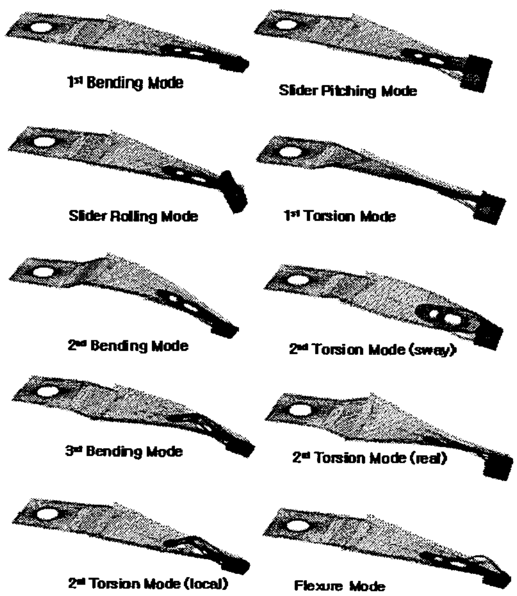

Fig. 2 Mode shapes of the suspension

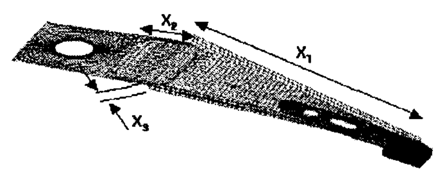

Fig. 3 Design variables of the suspension

2.4 Size optimization of HDD suspension

Generally, the most critical mode is sway mode and second torsion mode in the process of reading and writing data in HDD suspension as shown in Fig. 2. A thickness must become thicker to reduce the effect of two modes, however, stiffness of suspension must become smaller to be traced slider by disk. So, it is necessary to compromise because it is mutually contradictory. Accordingly, in this study, design parameters are selected to widen bandwidth of two modes by suspension shape as shown in Fig. 3. Object function is defined to increase two modes to target value as shown in equation (1), Where, target values are defined as 15% increased value of initial value each. Optimization is executed to minimize object function. Size optimization of the suspension has been used by using GENESIS. The optimized modal frequencies of the two modes are very close to the target values as shown in Table 3. Variation of design variables is shown in table 4. Due to variation of design variables, the suspension is designed to increase stiffness by object function as shown in Fig. 4.

Minimize

$$F = (\omega_{sway} - \omega_{sway}^{target})^2 + (\omega_{2nd\ torion} - \omega_{2nd\ torsion}^{target})^2 \tag{2}$$

2.5 Topology optimization of HDD suspension

The sway mode is the most critical mode in the process of reading and writing data and to optimize HDD suspension. It is necessary to maximize sway mode as shown in equation (3), (4). Load beam part and hatched area are only to be designed. Mass of suspension has to be more than 90% and 80% of initial value at least, as shown in equation (3), (4). Topology optimization of the suspension has been used by using GENESIS. Density method has been used to topology optimization by GENESIS.[8] The shape of load beam has been optimized and the edges of the ribs have been rounded in both cases as shown in Fig. 5,Fig. 6. The sway mode, which was the objective function, was hardly improved in both cases as shown in Table 6. Using size optimization can minimize object function as we expected but using topology optimization, which reduces mass of load beam partially, couldn't minimize object function properly. That is, topology optimization of the HDD suspension can't improve sway mode. Total masses of HDD suspension was reduced as show in Table 5.

Case 1 :

Minimize $$F = \frac{1}{\omega_{sway}} \tag{3}$$

Subject to $Mass \le 0.90\, Mass_{initial}$

$$\omega_{2nd\ torsion}^{initial} \le \omega_{sway} \le 1.15\, \omega_{2nd\ torsion}^{initial}$$

Case 2 :

Minimize $$F = \frac{1}{\omega_{sway}} \tag{4}$$

Subject to $Mass \le 0.80\, Mass_{initial}$

$$\omega_{2nd\ torsion}^{initial} \le \omega_{sway} \le 1.15\, \omega_{2nd\ torsion}^{initial}$$

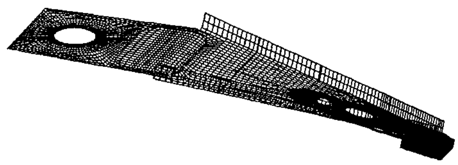

Fig. 4 Optimization shape of the suspension

Table 3 Result of size optimization : variation of natural frequencies

	Mode	Initial (Hz)	Optimum	Diff (%)
6	2nd Torsion (1)(sway)	6030	6842	13.5
8	2nd Torsion	8014	9221	15

Table 4 Result of size optimization : variation of design variables

	Initial (mm)	Optimum
X_1	13.61	13.306
X_2	3.23	3.139
X_3	0.36	0.769

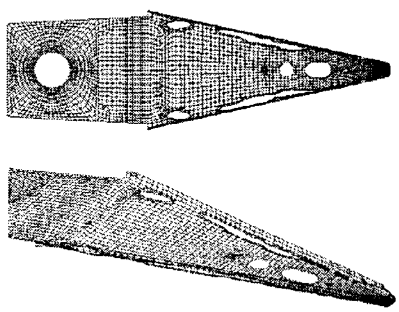

Fig. 5 Topology optimized suspension (Case 1)

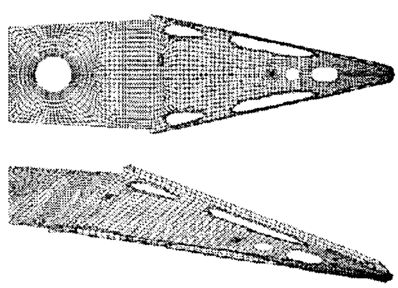

Fig. 6 Topology optimized suspension (Case 2)

Table 5 Result of topology optimization : variation of masses

	Initial (g)	Optimum	Diff (%)
Case 1: Mass ≤ 0.90$Mass_{initial}$	0.06	0.0549	9
Case 2 : Mass ≤ 0.80$Mass_{initial}$	0.06	0.0524	12

Table 6 Result of topology optimization : variation of natural frequencies

	Mode	Initial (Hz)	Optimum	Diff (%)
Case 1 : Mass ≤ 0.90 $Mass_{initial}$				
6	2nd Torsion (1)(sway)	6030	6151	2
8	2nd Torsion	8014	8017	0
Case 2 : Mass ≤ 0.80 $Mass_{initial}$				
6	2nd Torsion (1)(sway)	6030	6113	1
8	2nd Torsion	8014	8016	0

3. Optimization of ODD suspension

3.1 Shape of ODD suspension

Near-field recording technology is an advanced optical recording technology based on extremely small beam spot size. In this study, we select suspension head gimbal assembly that is made by LG which is composed of suspension, flexure, slider, base plate and PZT as shown in Fig. 7. Suspension is designed to give degree of freedom of normal direction motion and to protect vibration of lateral direction. PZT enables gap between base plate and suspension to move slightly Flexure is very flexible structure locates between load beam and slider to give degree of freedom on pitch and roll motion. Material properties and constants of the suspension are shown in Table 9.

3.2 FEA of ODD suspension

FEA has been used to analyze dynamic characteristics of suspension for free load. A finite element model of suspension is composed of 29924 elements and 31677 nodes. Natural frequency of developed finite element model is shown in table 10.

3.3 Size optimization of ODD suspension

Generally, the most critical mode is sway mode and second torsion mode in the process of reading and writing data in ODD suspension as shown in Fig. 8. A thickness must become thicker to reduce the effect of two modes, however, stiffness of suspension must become smaller to be traced slider by disk. So, it is necessary to compromise because it is mutually contradictory. Accordingly, in this study, design variables are selected to widen bandwidth of two modes by suspension shape as shown in Fig. 9. Object function is defined to increase two modes to target value as shown in equation (7), where target values are defined as 15% increased value of initial value each. Optimization is executed to minimize object function. The optimized modal frequencies of the two modes are very close to the target values as shown Table 11. Variation of design variables is shown in table 12. Due to variation of design variables, the suspension is designed to increase stiffness by object function as shown in Fig. 10.

Minimize

$$F = (\omega_{sway} - \omega_{sway}^{target})^2 + (\omega_{2nd\ torion} - \omega_{2nd\ torsion}^{target})^2 \quad (7)$$

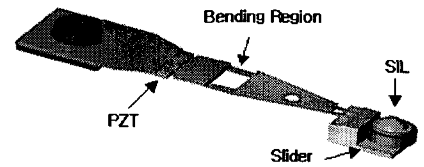

Fig. 7 Schematic of the ODD suspension assembly

Table 9 Material properties and constants of the suspension

Component	Material	E(GPa)	ρ(kg/m³)	ν	t(mm)
Load beam	Stainless steel	193	7500	0.3	0.076
Flexure	Stainless steel	193	7500	0.3	0.076
Slider	Ceramic	412	4300	0.27	4*3*1.2

Table 10 Natural frequencies of the suspension

	Mode	FEA(Hz)
1	1st Bending	93
2	Slider Rolling	589
3	Slider Pitching	625
4	1st Torsion	3285
5	2nd Bending	4389
6	**2nd Torsion**	8072
7	3rd Bending	8567
8	**Sway**	12506

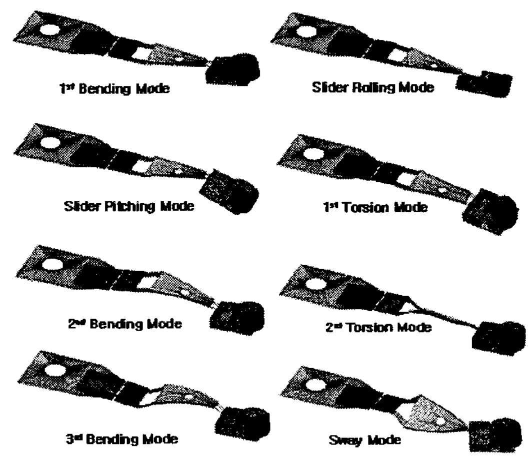

Fig. 8 Mode shapes of the suspension

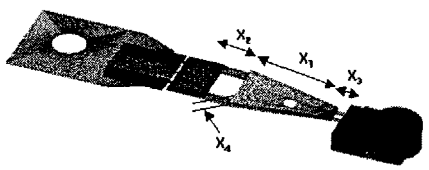

Fig. 9 Design variables of the suspension

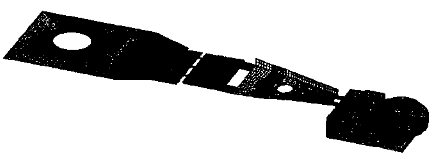

Fig. 10 Optimization shape of the suspension

Table 11 Result of size optimization : variation of natural frequencies

	Mode	Initial (Hz)	Optimum	Diff (%)
6	2nd Torsion	8078	9286	15
8	2nd Torsion	12507	14382	15

Table 12 Result of size optimization : variation of design variables

	Initial (mm)	Optimum
X_1	5.6	5.733
X_2	1.5	0.674
X_3	1.25	0.472
X_4	0.225	0.325

3.4 Topology optimization of ODD suspension

The sway mode is the most critical mode in the process of reading and writing data to optimize ODD suspension. It is necessary to maximize sway mode as shown in equation (8). Load beam part, bending region and flexure part are only to be designed. Mass of the suspension has to be more than 95% of initial value at least as shown in equation (8). The shape of load beam has been optimized as shown in Fig. 11. The sway mode, which was the objective function, was hardly improved in this case. Using size optimization can minimize object function as we expected but using topology optimization, which reduces mass of load beam partially, couldn't minimize object function properly. That is, topology optimization of the ODD suspension can't improve sway mode as show in Table 14. Total mass of ODD suspension was not reduced more than 1.5% as show in Table 13.

Case 3 :

Minimize $F = \dfrac{1}{\omega_{sway}}$ (8)

Subject to $Mass \le 0.95\, Mass_{initial}$

$\omega_{sway}^{initial} \le \omega_{sway} \le 1.15\, \omega_{sway}^{initial}$

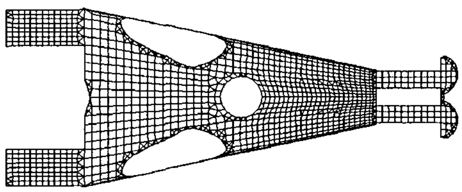

Fig. 11 Topology optimized suspension (Case 3)

Table 13 Result of topology optimization : variation of mass

	Initial (g)	Optimum	Diff (%)
Case 5: Mass ≤ 0.95Mass$_{initial}$	0.134	0.132	1.5

Table 14 Result of topology optimization : variation of natural frequencies

Case 5 : Mass ≤ 0.95 Mass$_{initial}$				
	Mode	Initial (Hz)	Optimum	Diff (%)
6	2nd Torsion	8078	8094	0
8	Sway	12507	12703	1.5

4. Conclusion

Shape of suspension is optimized to increase stiffness satisfying the object function as a result of size optimization. The size optimization of the suspension prevents the resonance by increasing the frequencies of HDD and ODD suspension more than that of servo system. It is able to improve information storage device performance, and especially develop disk drive having high track density. The sway mode can be improved by size optimization varying size but hardly be improved by topology optimization in reducing mass of load beam partially. As the result, using topology optimization, which reduces mass of load beam partially, couldn't minimize object function properly. In the future work, we will investigate with the robust design considering the manufacturing tolerance for the suspension.

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