Design and Analysis of a Suspension for OFH
In Small Form Factor ODD

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One of the trends on information storage device is focused on the development of small form factor optical disk drives with Optical Flying Head (OFH). Many different types of sliders for OFH and optical component systems have been introduced in the literature. However, the research about the actuating system is not much in the literature. In order for a slider with OFH to be successfully implemented in the system, a suspension is needed to be properly designed. Generally, a suspension supports slider performance, and tracking servo capacity in HDD. As the suspension supported the OFH slider which has larger mass and objective lens, it is required to satisfy shock performances for the mobility, and it also should meet the optical characteristics. In this study, the suspension for small form factor ODD is designed with sensitivity analysis. The dynamic characteristics of the suspension with OFH are analyzed finite element method and experiment, and the flying height and its variation of the OFH slider is measured by laser doppler vibrometer.

Key words: small form factor ODD, optical flying head, suspension, sensitivity analysis, flying height

1. Introduction

In recent years, new different types of optical storage devices have been developed and have appeared in the market. Today's storage devices pursue high capacity, compact size, low power consumption, reliability, and mobility. The micro optical disk drive can be a solution for compact size and mobility. For the contentment of these new demands in information storage devices, micro-optical disk drive with optical flying head has been created and developed. One of the major trends in micro-optical device is to merge the hardware systems and the technologies used in hard disk drive (HDD) and optical disk drive (ODD). Namely, optical fiber or small optical lens is used as read/write tool and suspension and swing arm, commonly used in HDD, is utilized as positioning mechanism 1)-2). Especially, when a small optical lens is used, it is mounted on a slider with an optical flying head. Although many optical performance issues on OFH have been discussed in the literature, mechanical dynamic performance issues, which are important in realizing micro optical disk drive as a system, have not been intensively discussed up to date. As a positioning actuator system for a micro ODD, can be used both a linear motor which is generally used in conventional ODD and a rotary motor which is used in conventional HDD. A swing arm type rotary actuator has advantages over a linear actuator in terms of fast access time for random access, slim size design, mobility, and anti-shock performance 3)-4).

Actuating system in the small form factor ODD consists of slider with fine focusing actuator and optical lens, suspension, and swing arm with optical component (block of optical unit; BOU) as shown figure 1.

In order to ensure adequate performance of the OFH such as flying stability and the bandwidth of the tracking servo, the suspension needs to be properly designed for mechanical performance. As obvious in HDD, the dynamic characteristics of a suspension determine the performances of a slider such as pitch, roll, yawing, and compliance modes. Further, the bandwidth of tracking servo is limited by the resonance frequency of the suspension in the lateral direction. In ODD, the torsional resonance mode of the suspension is also important for coma aberration, and the stiffness of the flexure part is needed to be low enough to achieve good flying stability, because the media of ODD has lower stiffness and rougher surface than that of HDD. Furthermore, the mass of the OFH is much larger than that of the slider of a conventional HDD. Therefore, it is not easy to increase the frequencies of the modes in the lateral direction. For the mobile application, the shock performance of the head-gimbal assembly should be guaranteed. In this study, the OFH slider and the suspension for ultra small ODD is designed and fabricated. The dynamic characteristics of the suspension with OFH are analyzed simulation and experiment.

2. Optical flying Head

For a small form factor optical drive, the OFH slider should be as small as possible, and stable head-disk
spacing should be guaranteed for reliable read/write operation of optical recording. The scheme of the OFH slider is shown in figure 2. The air bearing system (ABS) part is made of glass material for transmitting laser beam and focusing actuator is made of Si. The dimensions of the OFH are 1.6 mm width, 3.0 mm length, and 0.5 mm thickness. The ABS and the focusing actuator are fabricated by chemical etching process. The total mass of the OFH with objective lens is about 4.4 milli-grams. The slider has MEMS actuator to assist focusing motion of the objective lens and MO coil.

![Image](image_url)

**Fig.2** The scheme of the OFH slider

### 3. Design of Suspension for OFH

Rotary actuating system generally contains high performance electro-mechanical components and actuating mechanism. Suspension in the actuator mechanism connects the slider to the voice coil motor (VCM). OFH slider with high NA-lens and magnetic coil is located at the end of the suspension, and high accuracy and high speed positioning performances of the OFH slider depend on the dynamic characteristics of the suspension.

To increase the recording density, both linear and track density must be increased. Since the linear actuator of conventional ODD is replaced with a rotary actuator for high-speed small-size disk drive, access acceleration occurs in lateral direction of the suspension assembly. Therefore, the bandwidth of the positioning servo is limited by the resonant frequency of the suspension assembly in access direction. Further, the suspension system must be compliant enough to follow undulations in the disk and stiff enough for accurate and fast positioning of the OFH slider. Thus, it should be soft in three directions, i.e. vertical, pitch, and roll and stiff in the remaining directions, i.e. radial, tangential and yaw. The figure 3 shows the initial model of the suspension.

As shown figure 3, for the small form factor ODD, load/unload (L/UL) system is adopted. Load/unload mechanisms have been widely used in small form factor and removable information storage devices to avoid problems due to slider-disk stiction and wear. In this study, the initial model of suspension has the end-lift-tap and T-bar limiter for L/UL mechanism.

The suspension consists of three parts: load beam, flexure and base plate. The suspension itself has unique shape in order to reduce the mass and to decrease the frequencies of roll and pitch modes. The suspension has extended flexure structure. Generally, flexure structure is designed different thickness with load beam structure for the purpose of the stable slider’s flying performance, however the extended flexure take charge of the hinge structure. Therefore, the vertical stiffness and compliance of the slider is obtained at the same time. Moreover, the flexure has rectangular hole for the optical path and another rectangular hole which is located at the hinge for the reducing the mass and stiffness. The suspension is has the many holes arranged to optimize position for reducing mass and increasing stiffness. The initial model of the suspension has the load beam about 0.1 mm thickness, base plate about 0.2 mm, and flexure about 0.02 mm. The table 1 shows the sensitivity of the suspension.

**Table 1** Sensitivities of the initial model (Hz/mm)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cantilever</th>
<th>Roll</th>
<th>Pitch</th>
<th>1st Torsion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspension Length</td>
<td>-28.15</td>
<td>-228.09</td>
<td>-846.8</td>
<td>-225.97</td>
</tr>
<tr>
<td>Suspension Width</td>
<td>33.72</td>
<td>62.9</td>
<td>34.4</td>
<td>-251</td>
</tr>
<tr>
<td>Flexure Thickness</td>
<td>7306.8</td>
<td>76506</td>
<td>62390</td>
<td>166820</td>
</tr>
<tr>
<td>Load beam Thickness</td>
<td>-718.6</td>
<td>820</td>
<td>5018</td>
<td>259</td>
</tr>
<tr>
<td>Hole Radius</td>
<td>12.59</td>
<td>-4011.4</td>
<td>-4365.2</td>
<td>-727.6</td>
</tr>
<tr>
<td>Welding Position(X)</td>
<td>-0.04</td>
<td>236.6</td>
<td>39.6</td>
<td>10.5</td>
</tr>
<tr>
<td>Welding Position(Y)</td>
<td>-0.015</td>
<td>8.4</td>
<td>1.5</td>
<td>-0.4</td>
</tr>
</tbody>
</table>

Based on the sensitivities of the initial model, design parameters are selected as shown figure 4.

![Image](image_url)

**Fig.3** The initial model of the suspension

**Fig.4** The Design parameters of the Suspension
The final model is obtained by sensitivity analysis with seven design parameters. The target frequencies are 200 Hz for cantilever mode, 2.2 kHz for roll mode, 2.8 kHz for pitch mode, and 6.1 kHz for the 1st torsion mode. The cantilever mode is related with vertical stiffness, pitch and roll mode are related with the compliance of the slider's motion, and 1st torsion mode may occurred tilt error of the optical parts. After five optimizing iterations, each objective frequency converges to its final target within 1% error. Figure 5 show the process of the sensitivity analysis. The dashed line represents the target frequencies of the each modes, the solid line represents the iteration process.

Figure 6 shows modal analysis of the final designed suspension with unloaded state. For the finite element method (FEM), the ANSYS is utilized. The slider and base plate are modeled with SOLID45 elements, and the suspension is modeled with SHELL63 elements. The base plate is constrained to have zero displacement in the six DOF's in the modal analysis. The load beam and flexure are coupled at the dimple point with z-direction.

The stiffness of each direction at the slider is relevantly designed to the micro optical disk. The length of the suspension is suitable to the 1-inch micro drives. As the offset range is about 0.02mm and preload to the slider is 2.5gf, the bent angle of the suspension is 6 degrees. The thicknesses of the flexure and load beam are respectively 0.04mm and 0.1mm.

4. Analysis of Suspension for OFH

4.1 Modal analysis of the suspension

Fig. 7 shows the experimental setup for the experimental analysis. The Laser Doppler Vibrometer (LDV) is used for in-plane modal analysis, and scanning vibrometer is used for out-plane modal analysis. As the shaker excites the suspension, the LDV and scanning vibrometer are measured the frequencies of the suspension.

The table 2 shows the characteristics of the optimal suspension.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Stiffness Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring Rate(N/m)</td>
<td>20.43</td>
</tr>
<tr>
<td>Pitch Stiffness (uNm/deg)</td>
<td>15.3</td>
</tr>
<tr>
<td>Roll Stiffness (uNm/deg)</td>
<td>6.4</td>
</tr>
<tr>
<td>Mass (g)</td>
<td>1.28e-2</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>11.5</td>
</tr>
<tr>
<td>Bent Angle (deg)</td>
<td>6</td>
</tr>
</tbody>
</table>

The stiffness of each direction at the slider is relevantly designed to the micro optical disk. The length of the suspension is suitable to the 1-inch micro drives. As the offset range is about 0.02mm and preload to the slider is 2.5gf, the bent angle of the suspension is 6 degrees. The thicknesses of the flexure and load beam are respectively 0.04mm and 0.1mm.

The figure 8 shows the mode shapes and modal analysis results. For the vertical direction modal test, 100 nodes are measured by the scanning vibrometer. For the lateral
direction modal test, the center of the OFH slider is measured.

(a) cantilever : 230 Hz  (b) 1st bending : 3.11 kHz
(c) 1st torsion : 5.5 KHz  (d) 2nd bending : 6.82 kHz
(e) sway : 10.02 kHz

Fig. 8  Mode shapes and results

The frequency differences between the experimental and finite element analysis result do not exceed 10%.

4.2 Analysis of the probabilistic design system

Probabilistic analysis is a technique, which guarantees the reliable of final model considering the effect of uncertain input parameters of the model. Using a probabilistic analysis, we can find out how much the results of a finite elements analysis are affected by uncertainties in the model. This analysis is useful for the suitable manufacturing tolerance and material management. Accordingly, this analysis gives information about suitable design factors and reliability of the manufactured model.

Conventionally, the input data are uncertainty of the material properties, tolerance of the designed parameters, and boundary conditions. The results of the uncertain input are deflection, distribution of the stress or strain, and breakdown of the fatigue. The ANSYS, which is used commercial finite element method tool, is utilized for the probability results.

As the input uncertainty data, the thickness of load beam and flexure and manufacturing tolerance of the design parameters are considered. The distributions of those thicknesses are assumed as the gaussian distribution about 5% and the tolerances are considered as random step input. The static method is the combination of montecarlo method and response surface method. The figure 9 shows the input distribution of the thicknesses and tolerance.

(a) load beam thickness  (b) flexure thickness
(c) design parameter: LT  (d) design parameter: HH

Fig.9  Examples of distributions of the input data

The figure 10 shows the sensitivities of the input data. The cantilever mode is susceptible to the thickness of the gimbal and design parameter related to the width of the suspension(HH). The pitch mode is susceptible to the thickness and radius of hole. The 1st torsion mode is mainly susceptible to the thicknesses. The sway mode is susceptible to the most parameters.

(a) cantilever  (b) pitch mode
(c) 1st torsion mode  (d) sway mode

Fig.10  The sensitivities of each frequency

The figure 11 shows the histogram results of the variable input data. The tolerance about 20um, and 5% Gaussian distribution of the material properties may be obtained the fine results with satisfaction.
The frequency of the 1st torsion mode has an average of 6090 Hz, and the standard deviation is 217 Hz, which is a reliable variation. The frequency of the sway mode has an average of 9965 Hz, and the standard deviation is 338.4 Hz, which is also a reliable variation.

4.3 Analysis of the Shock Characteristics

As a disk drive becomes widely used in portable environments, one of the important requirements is durability under severe environmental conditions, especially, resistance to mechanical shock. An important challenge in disk recording is to improve disk drive robustness in shock environments. If the system comes into contact with an outer shock disturbance, the system can get critical damage in the head-gimbal assembly or disk. The focus of this section is to examine the shock response of the head-gimbal assembly when dropped. The phenomenon that drive makers would like to prevent is "head slap," which is triggered by a shock load that exceeds the suspension preload, causing the head to fly off the disk. While lift-off can result in read/write errors, the biggest concern is the permanent damage that occurs when the head slams back onto the disk. Indeed, it's not just the disk but the head and suspension that risk damage from head slap. Ultimately, head slapping will lead to drive failure of one kind or another.

The figure 12 shows the shock model of the suspension considering equivalent mass. As this method is obtained only the quantity of the shock performance, it is utilized the reaction force and equivalent mass. The table 3 shows the simulation results.

<table>
<thead>
<tr>
<th>Reaction force (uN)</th>
<th>135.77</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal gram load (mN)</td>
<td>24.525</td>
</tr>
<tr>
<td>Equivalent mass (mg)</td>
<td>13.84</td>
</tr>
<tr>
<td>Lift-off (1/g)</td>
<td>72.25</td>
</tr>
<tr>
<td>Head-disk separation acceleration (G)</td>
<td>177.19</td>
</tr>
</tbody>
</table>

4. Experimental Results

For the easy manufacturing, the many holes at the flexure structure are eliminated. The final suspension model is redesigned by sensitivity analysis. For avoiding manufacturing difficulties, we removed the holes at the flexure structure. The figure 13 shows the final suspension.

For the measurement of the flying height and the variation of the flying height, the two beams of the LDV are utilized. The figure 14 shows the experimental setup for the flying performance of the OFH slider.
The one measures the tip of the slider, and another measures the nearest point of the slider on the disk. The gram-load is 2.5 gf, and the linear velocity is 2.36 m/s. The figure 15 shows the experimental results through the low pass filter. As we want an average value of the flying height, the cut-off frequency of the low pass filter is 0.5 Hz.

![Fig.15 Experimental results for FH](image)

The flying height is about 240nm, and its variation is about 10% of the flying height.

5. Conclusion

The suspension for small form factor ODD is designed, and its dynamic characteristics are analyzed by simulation and experiment. After parameter study is previously studied, we selected the design parameters and compute sensitivity matrix. The sensitivity analysis is preceded for the optimal design. The designed suspension has higher 1st torsional frequency for prevent the tilt error and good compliance for stable flying performance of the OFH slider. The probabilistic analysis and static shock performance are simulated. The tolerance about 20um, and 5% Gaussian distribution of the material properties may be obtained the fine results with satisfaction, and designed suspension has 177.2 G head-disk separation acceleration. For the experimental, the modal analysis and flying height test are preceded. The modal test is comparison with the FEM result, the flying height characteristic is proved by the experiment. The suspension for OFH has the 1st torsional frequency of 61kHz, and the OFH slider has flying height of 240nm, and the flying height modulation is about 10% of the flying height.

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References


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