The Development and Performance Analysis of Beam Rotating Actuator for Multi-Beam Disk Drive

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Abstract

To enhance the effective data transfer rate the multi-beam optical disk drive is presented. The Beam rotating actuator is necessary for putting multi-beam on more than one track. Ray tracing was also executed for real system set-up. The Beam Rotating Actuator is made up of piezoelectric material, high stiffness wire hinge and dove prism. The actuator has about 1kHz resonance frequency and suitable operational range. The dynamic equation for the actuator is derived for the control of real system.

1 Introduction

A high-density and high-speed in optical disk has been always the development target for the next generation. For high-density is concerning, subjects of many studies are usually to develop new data storage method, to create new disk material, to enhance the performance of drive mechanism. As for high-speed, CD-ROM (Compact Disk-Read Only Memory) is very representative product and recently 52 times data transfer rate of general compact disk (CD) has been achieved. As an optical disk product with high density and high speed, digital versatile disk (DVD) had appeared at market in 1990s. Most DVD systems would have capability to read disk of both CD and DVD. Therefore, various CD/DVD compatible pickup heads have been presented.

On the another hand, owing to the speed limit of normal Disk drive's reading speed there are some trials to develop multiple reading disk drive's pick-up equipped multiple beam source. With these concepts we can achieve very high data transfer rate compared with normal disk drive's pick-up.

To accomplish this concept, we must adopt beam rotating actuator to adjust multiple laser sources (SEL; Surface Emitting Laser) onto the disk’s data track. These multiple beam disk drive’s proceed researches are as follows, Katayama[5] has composed optical source part and beam receiving part separately and fabricated cantilever type beam rotating actuator driven by VCM (Voice Coil Motor) method. Which system requires additional attachment components and has a complex shape to fix actuating coil. Tokumaru[6] has designed bearing supported rotating optical parts with trapezoid shaped dove prism and object lens. Which system has some shortage in fabrication of relatively high weight and low speed responses due to bearing movement.

In this paper, we discuss about high response beam rotating actuator using piezoelectric materials for multiple beam disk drive’s method. Objective of our research is to develop a new beam rotating actuator for multiple beam disk drives pickup. Thus we propose new beam rotating actuator concept and discuss about possibility as a new pickup system. Elastic joint and piezoelectric device is major characteristics of a new beam rotating actuator. The beam rotating actuator has abilities to rotate beam precisely and high responses. We suggest the model of beam rotating actuator for multiple beam disk drive's pick-up and execute the analysis for the dynamic characteristics. Finally a prototype of the actuator is made and the performance of the actuator is evaluated.

2 Multiple Beam Disk Drive’s Pick-up

The overall systematic configuration of multiple disk drive's pick-up is shown in FIG.1 the beam source from the SEL type semiconductor laser is focused on disk's
data track and optical pick-up reclaims the data beam on the beam receiving photo diode then transforms the electrical information data.

The main optical components of this multiple beam disk drive’s pick-up consists of multiple beam laser (SEL), collimator lens, dove prism, beam rotating actuator, objective lens, Photo diode array and astigmatism lens. For the power supply we use the external 5V DC input for laser source. The operating principle of the pick-up is that multiple beam from SEL laser source is converted into parallel lay beam by collimating lens and pass through the beam splitter. This beam should be rotated by dove prism adopted beam rotating actuator for the difference of angle due to the curvature difference of the optical disk’s track, to the compensation angle of optical axis adjustment and to the eccentricity of the disk.

Which beam passed the Dove prism is finally focused on the disk’s data track and read the data format then reflected on the disk surface. And the beam is finally reached to the photo diode array through the reverse beam path.

3 Beam Rotating Actuator

3.1 Actuating Device

We selected the high speed response, relatively precise small piezoelectric type actuating device NLA-5×5×1 type (by Tokin corp.) which accumulated 144 level 115μm thickness NEPEC-10 piezoelectric ceramic materials and electrodes with epoxy resin.

The maximum driving voltage of piezoelectric device is DC 100V and it has a displacement 15.0μm/100V at free end condition and exerts 87Kg fm/cm² forces. the static capacitance is 650nF. The stiffness coefficient of the piezoelectric material and displacement is calculated as each equations (1) & (2) considering piezoelectric coefficient (D33) which corresponds the displacement extension (Δt) per unit driving voltage, the elasticity coefficient of the piezoelectric material(CE), forcing area (A), thickness(t).

\[ F = AC_e D_{33} \frac{\Delta V}{t} \]

\[ \Delta \varepsilon = n \Delta t = nD_{33}V = \frac{\varepsilon D_{33}V}{t} \]

\[ = \frac{[\text{Field strength}] V}{t} \]

3.2 Actuating System

We designed the High Voltage Amplifier shown in fig 2 to generate the high voltage DC power for the piezoelectric actuator. For driving the actuator we generated the 0-10V range DC input then convert it with the High Voltage Amplifier range (0-85V) then achieve the displacement extension of the piezoelectric device through the strain gauge. The result of the piezoelectric material’s displacement is about 6μm.

![Multi-beam Optical Disk Drive System](image1)

![High Voltage Amplifier for Piezoelectric Element](image2)

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3.3 Fabrication of the Elastic Joint

To make a linear movement of the piezoelectric device into a rotational movement, there need pivot devices attached on the end point of the piezoelectric device. In that case to avoid the excessive shear forces and to reduce the back-lash effect which occurs normally with the mechanical joint we adopted the elastic joints which plays an mechanical joint part [7].

Newly designed Elastic joint has 3 degrees of freedom and using the 0.5mm high stiffness tungsten wire, molded into the acrly die so that the linear movement of the piezoelectric device would convert into the rotation movement of the beam rotating actuator. beam rotating actuator equipped with elastic joint is shown in fig. 3

To measure the exact piezoelectric device’s generating displacement we attached the strain gauge. (KFG-1—120-C1-I1L1M2R by Kyowa Corp.) the length of the strain gauge is 1mm, resistance is 119.6±0.4Ω, Gage factor is 2.13. and we used the Cyano-acrylate Based Adhesive for the attachment of the strain gauge.

3.4 Operating Range of the Beam Rotating Actuator

Most typical point of the multiple beam disk drive’s pick-up compared with usual disk drive is the presence of the Dove prism for the beam rotation. To make exact focus on the disk’s data track and proper beam alignment, multiple beam should be rotated according to the disk tracks. We should consider those compensation factors like those disk’s eccentric angle \( \theta_1 \), tangential angle difference due to the difference of the track radius \( \theta_2 \), the primary beam rotation angle for the adjustment of the optical axis \( \theta_1 \). And the total sum of the required beam rotation angle of the multiple beam is presented in the equation (3).

\[
\theta_b = \theta_1 + \theta_2 + \theta_3
\]

the beam rotation for the compensation of the disk’s eccentricity is caused by the discordance between the center of the disk and the center of the rotation axis. If we consider the rotation speed of disk \( (\omega) \), eccentricity of the disk \( (e) \); maximum 100 \( \mu m \) \), the relation between the movement of the central beam \( (e_b) \) and the eccentricity of the disk is shown in the equation (4)

\[
e_b = e \cdot \sin(\omega r)
\]

with the disk’s minimum available data recorded radius \( (r; 25mm) \) and formula(4), the required beam rotation angle for the compensation of the disk’s eccentricity is calculated as equation (5)

\[
\theta_1 = \frac{e}{r} \leq \frac{100 \times 180}{25000 \times \pi} = 0.23\\
\]

with the assumption that beam gap on the disk data track is 10\( \mu m \) and 3-beam source, overall beam gap length is 20\( \mu m \) and for the in case of normal CD-ROM the data recorded the inner radius of data recorded track is 23mm, outer radius of that is 58mm. the track pitch of the recorded data track is 1.6\( \mu m \) and according to the cosine 2\( \mu m \) formula, we can achieve the beam align angle difference as equation (6) & (7).

\[
\theta_{inner} = \cos^{-1}\left(\frac{23000^2 + 20^2 - 23003.2^2}{2 \times 20 \times 23000}\right)
\]

\[
\theta_{outer} = \cos^{-1}\left(\frac{58000^2 + 20^2 - 58003.2^2}{2 \times 20 \times 58000}\right)
\]

So the divergence angle of beam alignment \( (\theta_2) \) owing to the difference of the inner and outer curvature of the disk is derived as equation (8).

\[
\theta_2 = \theta_{outer} - \theta_{inner} = 0.015\\
\]

And the rotation angle \( (\theta_3) \) for the adjustment of
The optical axis is within 0.3°, so the overall rotation angle (θ) of the multiple beam on the disk surface is within 0.55°. On that purpose we come to an conclusion that operating range of the beam rotating actuator should be over 0.28° which is the half value of the multiple beam rotation angle.

3.5 Beam Rotating Actuator

We designed and fabricated the beam rotating actuator using piezoelectric device, dove prism, and elastic pivot joint. According to the pivoted elastic joint length (λ2), length difference of the attached pivot point from the optical axis (λ1), and the displacement of the piezoelectric device (Δλ), the rotating angle (Δθ) is calculated in the equation (9).

\[ \Delta \theta = \tan \left( \frac{\lambda_2 + \Delta \lambda}{\lambda_1} \right) - \tan \left( \frac{\lambda_2}{\lambda_1} \right) \]  

The body of the beam rotating actuator is made up of stainless steel material which can endure the generated force of the piezoelectric device. The piezoelectric material is attached on the body using epoxy resin for high stiffness and molded the tungsten wire into the acryl die. This elastic joint has overall 8.2mm length including acryl die and finally assembled beam rotating actuator is shown in Fig. 4.

4. Measurement of Actuator’s Performance

4.1 Characteristics of Beam Rotation

To verify the performance of the beam rotating actuator we need to test if the beam rotating actuator could rotate proper angle of the beam from the SEL laser source. The required beam rotation angle is such a small value calculated previously that instead of measuring the rotating angle of the actuator directly we measure the beam spot on the 3m away screen. So we could measure the difference of the beam movement on the screen then calculate the beam rotation angle of the beam rotating actuator.

In this case, according to the rotating angle of the actuator (Δθ), beam movement on the screen (Δx), distance between beam rotating actuator and screen (λ) the following equation (10) is achieved.

\[ 2\pi \lambda \frac{2\Delta \theta}{360} = \Delta x \]  

\[ \Delta \theta = \frac{90 \Delta x}{\pi \lambda} \]  

Fig. 5 shows the rotational performance of the beam rotating actuator when 0–10Vcomputer D/A converted input applied to the actuator through the high voltage amplifier. Which result shows the linear performance of the beam rotating angle between the input power and the output rotating angle. With the maximum input power the maximum beam rotation angle of the actuator is about 0.63°.

![Fig. 4 Assembled Beam Rotating Actuator](image)

4.2 Frequency Response of the Beam Rotating Actuator

We tested the beam rotating actuator in the point of frequency domain if the fabricated actuator could have a performance along the controllable frequency range. If we consider the young’s modulus of the actuator (E), moment of inertia of the actuator (I) and the other coefficient, the natural frequency of the actuator is derived as equation (11).

\[ \delta = \frac{Pl}{EI}, \quad K = \frac{EI}{I} \]  

\[ \omega_n = \sqrt{\frac{K}{m}} = \sqrt{\frac{EI}{Im}} \]  

then we substitute the value of the young’s modulus (E) 193Gpa, moment inertia(I), the mass of the dove prism(m) and finally calculate the resonance frequency of the actuator, that is about 1.12kHz.

For the real systematic experiment for the frequency response we utilized the OFV 1102 laser interferometer.
(Polytec corp.) and added the sweep sine (range 2Hz–5kHz) signal to the high voltage amplifier with the digital signal analyzer then calculate the frequency response characteristics of the beam rotating actuator

![Graph](image)

**Fig. 5 Beam Rotation Performance**

![Graph](image)

**Fig. 6 Frequency Response of the Actuator.**

![Graph](image)

**Fig. 7 Curve Fit of Frequency Response**

Fig. 8 shows the frequency response characteristics of the beam rotating actuator when 30V DC input sweep signal applied to the actuator through digital signal analyzer. The resonance frequency is detected on the range about 1.0034kHz.

We presented the Curve fitted frequency response with mathematic calculation in Fig. 9 then with the gain of the system we derived the transfer function of the beam rotating actuator in equation (12). In this equation ($\theta/\theta_i$) and (Vi) each represents the beam rotating angle [°], and the driving input voltage[V].

$$\frac{\theta}{\theta_i} = \frac{10.6}{s^2 + 3.23E2s + 6.20E5}$$  \hspace{1cm} (12)

When we consider the maximum rotation speed of the disk as 3000rpm, the resonance frequency of the beam rotating actuator should be over about 50Hz and fabricated actuator has about 1kHz resonance frequency characteristics. Which means that fabricated beam rotating actuator could be applicable enough to the multiple beam disk drive's pick-up set up.

4.3. Beam rotation performance

Fig. 8 shows the experimental setup to carry out the beam rotation performance test and the frequency response test also.

![Image](image)

**Fig. 8 Overview of Experimental Set-up**

![Image](image)

**Fig. 9 Beam Spot Scope on the Disk (CCD) Plane**
At the experiment we integrated the all the needed components to fabricate the multiple beam disk drive including collimator lens, dove prism, objective lens, beam rotating actuator. and we lay CCD camera instead of placing the real compact disk to verify if the beam from the SEL laser source could be focused on the disk surface and have a good rotating performance.

Then we tested the completed system. Captured beam spot rotation movement is shown on the CRT display. In that case, the beam rotation performance of the disk plane was exactly 2 times of the beam rotating actuator’s rotation angle.

5 Summary

We have designed the beam rotating actuator which is applicable to the multiple beam disk drive’s pick-up and fabricated the beam rotating actuator with piezoelectric device and elastic pivot joint.

We can describe the main advantage of this actuator as follows, with less friction we can get high response and precision beam rotating angle. Relatively simple and less expensive and less difficulty in the point of manufacturing. We adopted the elastic pivot joint to convert the linear movement of the piezoelectric device into the rotational movement of the beam rotating actuator.

The fabricated beam rotating actuator shows the linear output characteristics according to the input voltage. Through the frequency response test and beam rotation angle range test we concluded that designed beam rotating actuator could be applicable to the multiple beam rotating disk drive’s pick-up head for higher data transfer rate as well as for higher reading speed.

References


