Crosstalk of High-precision Optical Pickup Actuator with Optimal Structure Parameters

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Abstract: The crosstalk characteristic is a key factor that affects the pickup actuator dynamic property and consequently the accuracy of reading and writing operation in the future ultra-high density optical storage systems. In this paper, the actuator spatial magnetic field distribution model is first established. Then the crosstalk movement phenomenon of the actuator is analyzed and simulated in CST software based on FDTD principle. Moreover, the crosstalk degree in both tracking and focusing directions are defined with respect to the produced crosstalk forces. The relationship between the crosstalk degree and the structure parameters of the actuator such as the height and width of the permanent magnet is analyzed. Taguchi orthogonal method is further used to obtain the optimal structure parameters. It is concluded that the crosstalk can be effectively reduced by an optimal design of the structure parameters, thereby, the dynamic performance of the actuator can be improved.

Keywords: Optical storage, Pickup actuator, Crosstalk degree, Ultra-high density, Structure parameters.

1. Introduction

With the ultra-high density and higher data transfer speed in the next generation optical storage systems, a strict demand of the actuator movement accuracy and dynamic performance is required accordingly. For example, in the next generation near field optical storage systems the distance between the objective lens and disc will drop down to less than 100 nm, which necessitates a very high position servo accuracy [1]. Crosstalk characteristic between each movement direction is a common drawback in the traditional optical pickup actuators, since it not only results in the decline of the reading and writing performance, but also could cause a collision between the objective lens and the disk.

In the typical two-dimensional actuator as shown in Fig. 1, the movable parts are supported by both the suspension wires and the electromagnetic force, which performs the two-dimensional movements, such as focusing movement and tracking movement [2-4].

The focusing movement should make the objective lens move in the direction perpendicular to the optical disc surface. In addition, the tracking movement should control the objective lens to move in the direction parallel to the optical disc surface. However, the movement in one direction could cause crosstalk in the other direction due to the non-uniformity of the magnetic field.

2. Spatial Model of the Magnetic Field

The force on the actuator is decided by the distribution of the electromagnetic field. Therefore,
the analysis of the electromagnetic field is critical to optimize the dynamic characteristic of the actuator [5, 6]. Generally, the two-dimensional wire actuator's spatial magnetic field is mainly composed of a magnetic field generated by two permanent magnets, a magnetic field generated by the focusing coil and a magnetic field generated by the four tracking coil, as shown in Fig. 2. In the initial state, the permanent magnets, the focus coil and tracking coil share one geometric center denoted as point \( O(x_i, y_i, z_i) \). When they move away from the central location, their geometric centers will be denoted as \( O_1(x_i', y_i', z_i') \), \( O_f(x_f', y_f', z_f') \) and \( O_t(x_t', y_t', z_t') \), respectively.

![Fig. 1. Various views of the two-dimensional wire actuator.](image1)

![Fig. 2. Diagram of the actuator coils.](image2)

2.1. Spatial Magnetic Field Model of Permanent Magnet

According to the theory of medium magnetization, \(-\nabla \mu_0 \cdot M\) was regarded as a hypothetical magnetic charge density for computing the magnetic field of the permanent magnet. In the permanent magnet which is magnetized uniformly, surface charge only exit on the surface of magnetic medium. The surface magnetic charge density \( \sigma \) is:

\[
\sigma = \mu_0 \cdot \tilde{M} \cdot \tilde{n},
\]

(1)

The permanent magnet actuator is shown in Fig. 3. Assume that the permanent magnets are uniformly magnetized, the two opposite surfaces II, III are magnetized as N pole, the other two surfaces I and IV are magnetized as S pole. According to the equivalent magnetic charge method, unit magnetic charge at the point \( P(x_i, y_i, z_i) \) on the surface generates magnetic flux at any point in the space. The magnetic induction of any point \( P(x, y, z) \) generated by the point \( P(x_i, y_i, z_i) \) on the surface I, can be expressed as:

\[
\overline{dB_i} = \frac{1}{4\pi \rho_i} \frac{\sigma_i^2}{dA_i},
\]

(2)
where $r = (x-x_i)i + (y-y_i)j + (z-z_i)k$ can be computed according to the magnetic field superposition principle. According to the superposition of the magnetic field of the permanent magnet, magnetic field distribution generated by each surface can be obtained by the integral.

### 2.2. Spatial Magnetic Field Model of Focusing Coil and Tracking Coils

Coils of actuator are wounded by the conductor. The analysis can be performed according to the electromagnetic field produced by the current source. Biot-Savart law states that the magnetic induction of any point $p$ generated by the current element $I dl$ is proportional to the current element, and proportional to the sine of the angle $\theta$ between the current element $I dl$ and the vector $r$ from the current element to the point of $p$, and inversely proportional to the square of the size of the vector:

$$dB = \frac{\mu_0}{4\pi} \frac{I dl \times r}{r^3} dV,$$

where $\frac{\mu_0}{4\pi}$ is the proportional coefficient, $\mu_0$ is the permeability of vacuum, and its value is $\mu_0 = 4\pi \times 10^{-7} \text{N} \cdot \text{A}^{-2}$.

The structure of the focusing coil is shown in the Fig. 4. The height, width and length of focusing coil are denoted as $a$, $b$ and $c$, respectively.

The expression of the magnetic field generated by the four coils can be obtained by the integral in the corresponding volume. The magnetic field generated by the tracking coils, as shown in Fig. 5, can be obtained in the same way.

### 2.3. The Spatial Overall Magnetic Field

Similar to the above analysis for each part, the total magnetic field is also in line with the principle of superposition. The magnetic field at any point $P(x, y, z)$ in the actuator space is as follows:

$$\mathbf{B}(P) = \mathbf{B}_f + \mathbf{B}_t + \mathbf{B}_o$$

$$= \sum \int_S \frac{\sigma}{4\pi} \frac{\mathbf{r}}{r^3} dA_s + \sum \int_V \frac{\mu_0}{4\pi} \frac{\mathbf{j} \times \mathbf{r}}{r^3} dV_i$$

$$+ \sum \int_V \frac{\mu_0}{4\pi} \frac{\mathbf{j} \times \mathbf{r}}{r^3} dV_t$$

### 3. The Simulation Results of the Spatial Distribution of Magnetic Field

Based on the analysis of spatial magnetic field model, the full results of magnetic field distribution...
can be observed through numerical simulation. There are several software products that can be used to calculate the electromagnetic field. The Ansoft from United States based on the finite element analysis and German CST software based on the finite-difference time-domain method are the popular ones. In this paper, the EM STUDIO module of CST software is used to analyze the spatial electromagnetic field of the actuator.

The main parameters of the permanent magnet, focusing coil and tracking coil in the simulation are listed in the Table 1. The simulation results are shown in Fig.6-9.

<table>
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<th>Material</th>
<th>Parameter1</th>
<th>Parameter2</th>
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<tr>
<td>Permanent Magnet</td>
<td>Relative permeability 1.06</td>
<td>Remnant flux density (T) 1.4</td>
</tr>
<tr>
<td>Focusing coil</td>
<td>Current 0.3 (A)</td>
<td>56 turns</td>
</tr>
<tr>
<td>Tracking coil</td>
<td>Current 0.3 (A)</td>
<td>56 turns</td>
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Table 1. Parameters of permanent magnet, focusing coil and tracking coil.

![Fig. 6. The simulation result of the permanent magnets.](image)

![Fig. 7. The simulation result of the focusing coil.](image)

![Fig. 8. The simulation result of the tracking coil.](image)
Fig. 9. The overall simulation result of the actuator.

Through the simulation, it can be concluded that the magnetic field of the actuator is symmetric to the center of the actuator but not uniform. When the movable parts move in the non-uniform magnetic field, they deviate from the desired center position. Namely the movable part is not only actuated in the expected direction, but also is actuated in another direction caused by the asymmetric magnetic field, which results in a crosstalk movement [7].

4. Analysis of Crosstalk Degree of the Actuator

The tracking coils and the focusing coils are the movable parts of the actuator. \( O_e(x_e,y_e,z_e) \) is set as the geometric center of the movable member. The force of the current element in the coil is expressed as:

\[
d\vec{F} = \vec{J} \times \vec{B} dV,
\]

where \( \vec{J} \) is the current density vector of the current element, \( \vec{B} \) is the space magnetic field vector of the current element as \( \vec{B} = B_x \hat{i} + B_y \hat{j} + B_z \hat{k} \). \((x,y,z)\) is the coordinate of an arbitrary current element [8]. The rotational torque generated by the movable parts is:

\[
d\vec{M} = r_e \times d\vec{F} = r_e \times (\vec{J} \times \vec{B}) dV,
\]

where \( r_e = (x-x_e) \hat{i} + (y-y_e) \hat{j} + (z-z_e) \hat{k} \). The forces on the focusing coils and tracking coils are represented as:

\[
\vec{F}_f = \sum \int \int r_e \times (B_i \hat{i} + B_j \hat{j} + B_k \hat{k}) dV,
\]

\[
\vec{F}_t = \sum \int \int r_e \times (B_i \hat{i} + B_j \hat{j} + B_k \hat{k}) dV,
\]

Electromagnetic torque on the movable parts can also be obtained:

\[
\vec{M}_f = \sum \int \int r_e \times (\vec{J}_f \times (B_i \hat{i} + B_j \hat{j} + B_k \hat{k})) dV,
\]

\[
\vec{M}_t = \sum \int \int r_e \times (\vec{J}_t \times (B_i \hat{i} + B_j \hat{j} + B_k \hat{k})) dV,
\]

\[
\vec{M} = \vec{M}_f + \vec{M}_t = M_i \hat{i} + M_j \hat{j} + M_k \hat{k},
\]

where \( B_x, B_y, B_z \) are the components in three directions of the magnetic induction vector \( \vec{B} \). \( \vec{J}_f \) and \( \vec{J}_t \) are the current density vectors of the focusing coil and tracking coil, respectively. \( r_e \) is the vector from current density element to the centroid \( O_e \).

When the movable part moves in the spatial magnetic field, the centroid deviation from the center position will cause un-balanced forces on the movable part due to the non-uniformity of the spatial magnetic field. As shown in Fig. 10, when the movable part of the actuator moves in the focusing direction, the focusing force can be expressed as:

\[
F_{fz} = F_{f1} + F_{f2} + F_{f0} + F_{f02},
\]

The space magnetic field is no longer symmetric when the movable part deviates from the center position in the tracking direction. The force generated in the Z direction cannot be completely balanced, namely, \( F_{fz} \neq 0 \). Therefore, a crosstalk force \( F_{tc} \) in the tracking direction will be generated at this point. Consequently, the crosstalk movement in the focusing direction is generated.

\[
F_{fc} = F_{fz} - F_{tc},
\]

It is similar to the focusing coils. The tracking driving force \( F_{td} \) and crosstalk force \( F_{tc} \) will be generated when the actuator moves in the tracking direction.
The driving force and crosstalk force of the focusing coils and tracking coils are related not only to the height and width of the structural parameters but also to the deviation displacement from the center position [9]. In the following, a crosstalk degree is considered at the point where the biased displacement is selected as 0.2 mm. Crosstalk degree is defined as the mean value of the ratio of the crosstalk force and the driving force when the biased displacement in the focusing direction or in the tracking direction is set as 0.2 mm, respectively.

\[ CD = \left( \frac{F_{fc}}{F_{fd}} + \frac{F_{tc}}{F_{td}} \right) / 2, \]  

The change trend of the crosstalk degree with the variation of the structure parameters can be obtained from the figure, which shows the crosstalk degree is first increased and then decreased. In the simulation, only one of the parameters is changed and the other two parameters are fixed, which are set as \( W = 2.0 \text{ mm} \) and \( H = L = 5.0 \text{ mm} \), so that the optimal structure parameters can’t be obtained directly based on the results in Fig. 10-13. Taguchi orthogonal method is further applied in this paper and totally 25 samples were carried out in order to get the optimal structure parameters [10].

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5. Conclusion

In this paper, the distribution properties of the actuator spatial magnetic field is analyzed and
simulated by the CST software based on FDTD principle. The essential cause of the crosstalk characteristic in the actuator is investigated. The concept of crosstalk degree is defined in order to investigate the effects of the crosstalk characteristic. Based on the simulation result, the crosstalk degree variations with the change of actuator structure parameters including the height, the length and the width of the permanent magnet are analyzed, and consequently the optimal structure parameters are obtained with the desired minimum crosstalk degree through the Taguchi orthogonal array method.

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References


