

STUDY ON THE DYNAMIC TILT CHARACTERISTICS OF OPTICAL PICKUP ACTUATORS CONSIDERING ELECTROMAGNETIC NONLINEARITIES USING COUPLED-FIELD ANALYSIS

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Abstract

An optical pick-up actuator is an objective lens moving device that provides means to accurately follow the track of a disc with constant working distance. It is composed of a moving part and magnetic circuit part. The moving part supported by suspensions is actuated in 3-axis motions by Lorentz force which is generated by magnetic circuit. When an actuator follows the deflection of a disc, unbalanced force distributions may occur on the moving part by magnetic nonlinearities. This phenomenon deteriorates the static and dynamic tilt characteristics of the actuator. If the dynamic tilt shows nonlinear characteristics, the actuator has insufficient tilt margin to follow disturbed disc motions. According as an optical storage becomes high-density as in the Blu-lay or HD-DVD, an adequate tilt margin analysis and exact frequency response prediction becomes key design factors to determine the static and dynamic performance of an actuator. Since the previous studies only treated the linear characteristics of tilt, they provide us with inaccurate results. In this paper, considering structural as well as magnetic nonlinearities, we predicted tilt properties in all moving ranges and thus we were able to obtain more acceptable results by finite element method. First, we analyze magnetic nonlinearities at each position. Second, on the basis of magnetic analysis results at the first step, we predict exactly dynamic tilt properties of the moving part with the calculated magnetic nonlinearities. The frequency response was also quite well evaluated by coupled-filed analysis. Finally, we verified our proposal by comparing the numerical results with those of experiment.

1. INTRODUCTION

Data storage capacity of optical discs becomes higher due to recent rapid developments in the fields of multi-media and digital broadcasting. To read information stored in high-density optical discs, optical heads should use a laser with shorter wavelength and lens with higher numerical aperture (NA). Consequently, the disc tilt margin with respect to the wave front aberration becomes tighter. For high-density optical discs, it is required to use a laser diode with

shorter wavelength (λ) and objective lens that has a higher numerical aperture (NA) to reduce the spot size of the laser beam focused on the disc. However, the tilt margin of optical systems becomes lower because the tilt margin is proportional to λ / (NA³) for the same substrate thickness of the disc. In addition, optical pickups such as CD/DVD and/or DVD/BD compatible pickups may require different optimal tilt conditions. Also, for higher density data storage than BD, NFR (Near Field Recording) system is also being studied as a solution to post HD. Especially, the NFR requires tighter tilt margin than any other optical data storage systems. The NAs of each format are 0.45 (CD), 0.60 (DVD), 0.85 (BD) and 1.5 (NFR), respectively as shown in Figure 1.

As the actuator moving tilt have a bad influence on read/write characteristics, the dynamic tilt characteristics become a more important design factor in high-density data storage system. To read theses various high-density optical discs, we must use the moving mechanism called optical pick-up actuator which is composed of moving part and magnetic circuit part. The actuator follows the track of a disc with constant working distance and the tilt of disc.

The optical pick-ups for high definition using blue laser which has been developed recently has more complicated optical layouts in order to additionally deal with CD/DVD discs using the red laser for the backward compatibility. In optical pick-ups, the actuator plays an important role for the tilt characteristics of a system. When an actuator follows disc in the focus and track directions, the tilt must be suppressed.

In this research, first, we compared conventional tilt prediction methods for actuators considering only structural linear aspects of supporting part with the proposed method which considers nonlinear characteristics of supporting part and magnetic circuit part, simultaneously through coupled-filed analysis. The conventional tilt prediction methods only consider unbalanced Lorentz forces which are generated by magnetic circuit part within actuator moving range without considering large deformations of wires. However, in order to analyze the tight tilt margin of an optical pick-up system, the tilt must be predicted more precisely. Therefore, contrary to the conventional prediction methods, the nonlinearity of Lorentz force which is generated with different values at each actuator position and structural nonlinearity which has different stiffness at each actuator position are considered, simultaneously in calculating the tilt characteristics of actuators. We can obtain more accurate results through coupled-filed analysis considering structural and magnetic force nonlinearity, simultaneously. The static and dynamic characteristics of the actuators developed using the proposed method were investigated.



Figure 1. Explanation of the numerical aperture with respect to each optical data storage format

2. DEFINITION OF DYNAMIC TILT

The tilt of actuator can be occurred when it follows disc maintaining working distance. When actuator moves to follow wobbled disc, for example, unbalanced Lorentz force of magnetic circuit is occurred by resultant torque of focusing system and tracking system. Therefore, unexpected tilt, called dynamic tilt, is arisen.

In this actuating system, movement range is within a sub-millimetres and thus even if the tilt value is too little, its influence to pick-up optical system is high. Therefore, we need to strict calculation and prediction about the tilt to improve optical performance, because this phenomenon distorts the optical axis and thus it can reduce performance in reading and writing data. Thus, it is important to analyze the tilt at early design stage for the tilt margin for high density disc formats.

3. COUPLED-FILED ANALYSIS OF ACTUATOR

3.1 Finite element model of actuator

The actuator can be classified into two parts, magnetic circuit part and moving part. Magnetic circuit part generates Lorentz force to actuate a moving part. The moving part follows a disc track while maintaining constant distance between an objective lens and a disc. The previous method for predicting the dynamic tilt is to calculate Lorentz force, firstly. Then, from the result of magnetic circuit analysis, we apply point forces to coils which are attached to moving part. This method considers only structural linear effects, which leads to over-estimated results. Therefore, in this paper, we performed analysis, coupled-filed analysis, using integrated magnetic circuit and moving part as shown in Figure 2.



Figure 2. 3D and finite element model of actuator

3.2 Coupled-field analysis of actuator

Coupled-field analysis is method to analyze magnetic and structural part simulation in one model. Through the magnetic analysis result at each driving coil position of a moving part, the direction and magnitude of Lorentz force at each node of coils are determined, previously. Then, it can be sequence applied for the next structural analysis step without any loss of analysis data. We can analyze movements of the structural part through applying currents and we can also predict the dynamic tilt and frequency response from this method precisely.

In this work, we compared the experimental results with those by simulation in order to validate the proposed coupled-field analysis, where we obtained the displacement of moving part in the focus and track directions according to the DC sensitivity. In Table 1, we presented the DC sensitivity results of the moving parts by using the proposed analysis method, which shows a good agreement with experimental result.

4. TILT CALCULATION

4.1 Linear FEM analysis

Linear FEM analysis method does not consider structural nonlinearities and only consider the number of wires, the vertical and horizontal distances between wires, wire stiffness and effective wire length as shown in Figure 3. In this method, we obtain Lorentz force at each positions of moving parts and apply the resultant torque induced by Lorentz forces in focusing and tracking direction to moving part which is located at initial position. Then, we calculate rotating angle using simple mathematics considering rotational stiffness of wire at initial position. Therefore, it can be easily and quickly calculated without nonlinearities existing in the real model.

	Focus	Track		
Experiment	1.291 mm/V	1.202 mm/V		
FEM analysis	1.268 mm/V	1.184 mm/V		
Error	1.78%	1.49%		

Table 1. Comparison of DC sensitivity per unit voltage





 L_{radial} : radial direction Length between wire L_{focal} : focal direction Length between wire L_{effect} : wire effective length E : young's modulus I : area moment of enertia

Figure 3. Simple mathematical modeling

4.2 Proposed FEM analysis

In order to realize the same situation of the dynamic tilt by movement of structural parts, we first find energy equilibrium position between strain energy of wire and magnetic energy by Lorentz force through iterated analysis in the tracking direction. This energy equilibrium position is not determined by displacements of moving parts through initially applying currents but by energy equilibrium position through magnetic analysis iteratively at each position. Then, while maintaining calculated prestress is in wires at the position, we find the energy equilibrium position in the same way as we did in the track direction.

We can obtain the tilt angle from the coordinates of each point as shown in Figure 5. For this calculation, we divided the lens into four pieces, because it can create nodes at the exact points which we want to measure.



Figure 4. Analysis procedure of linear method and nonlinear method



Figure 5. Calculation point of tilt point



Deformation in the Focus Direction

Deformation at Final Position

Figure 6. Final position of deformation



Figure 7. Differences between linear and nonlinear stiffness

	Tilt Angle		
Conventional Linear	0.0876°		
FEM Analysis Method			
Proposed Nonlinear	0.075°		
FEM Analysis Method	0.075		
Experimental Result	0.055°		

Table 2	Tilt angle	calculated by	v each	method	and the	experimental	result
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Table 3. Comparisons of analysis results by each method

	Error
Method I : Simple Approximation Analysis Method	37.0%
Method II : Geometric Linear and Magnetic Nonlinear Coupled-Field Analysis Method	37.3%
Method III : Geometric Nonlinear and Magnetic Nonlinear Coupled-Field Analysis Method	27.7%

Figure 7 shows why the differences between the results of linear and nonlinear analysis. In the figure, the linear stiffness is calculated as the rotational angle divided by the unit applied torque in the original position.

On the other hand, the nonlinear stiffness, whether it is a clock-wise or counter-clock-wise, is obtained by first translating the moving part in the focus and track direction, sequentially considering pre-stress according to each position, and then applying unit torque.

6. FREQUENCY RESPONSE ANALYSIS

When we analyze frequency response of actuator, we usually apply a point load from magnetic circuit analysis to the coils. However, this method can not reflect total force distribution and leakage of B-flux. If shape of yoke is complex or using included yoke, we must consider leakage of B-flux for exact results. In order to improve accuracy of the analysis, we must consider these aspects strictly. Coupled-filed analysis permits to analyze considering these aspects. Coupled-filed analysis can apply distributed force which is considered all directions to coil. Also, there are no losses from magnetic flux. Using this method, we could analyze our actuator model precisely. Comparing with previous frequency response analysis method, we obtained more exact results, compared to experiments. Measured frequency response on the objective lens is shown in Figure 8. In the end, a reinforcement process of the structure allowed the resonance frequency of beyond 30 kHz and the gain margin (the gain difference from 1 kHz to the resonance frequency) of more than 45dB.



(a) Focusing Direction

(b) Tracking Direction

Figure 8. Frequency response analysis of actuator

7. CONCLUSIONS

In this paper, we proposed tilt analysis method and compared the previous tilt analysis method. Previous tilt analysis methods considered only magnetic nonlinearities without structural nonlinearities, pre-stressed by deformation of wires. Proposed methods lead to consider both of them through coupled-filed analysis. Through the proposed tilt analysis method, we could understand about the tilt generation mechanism of optical pick-up actuators and developed an actuator for high density optical pick-ups which suppresses the tilt effectively. Finally, we obtained more exact results of frequency response analysis through coupled-field analysis.

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