Design of Moving Magnet Type Optical Pickup Actuator with High Frequencies of the Flexible Modes

높은 유연 모드 주파수를 갖는 가동 자석형 광 픽업 액추에이터 개발

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Key Words : Moving Magnet Type(가동 자석형), Actuator(액추에이터), Flexible Mode(유연 모드), Electro-magentic Circuit(전자기 회로), Design of Experiment(실험계획법)

ABSTRACT

Data transfer rate and storage capacity are main criteria of the performance of the optical disk drive. The highest data transfer rate and the largest storage capacity is most desirable. To increase these performances, the actuator of the optical disk drive should have a high servo bandwidth to compensate the vibration of an optical disk. The servo bandwidth is limited by some flexible modes of the actuator, thus it is essential to increase the natural frequencies of the flexible modes. In this paper, we suggested a moving magnet type actuator having high frequencies of the flexible modes. Generally, the moving magnet type actuator has an advantage to increase the natural frequencies of the flexible modes because the moving magnet type actuator has simple structure and the Young's modulus of magnet is high. However, large moving mass and inefficiency of EM(electromagnetic) circuit cut down driving sensitivities of the actuator. To improve driving sensitivities, we designed the model with the closed electromagnetic circuit for tracking direction. In addition, driving sensitivities and the natural frequencies of the flexible modes were improved by using DOE(design of experiments) for electromagnetic circuit and modifying the lens holder.

요 약

데이터 전송률과 저장용량은 광학디스크드라이브 성능의 주요 척도이다. 데이터 전송률은 높을수록 좋으며, 저장용량은 되도록 큰 것이 바람직하다. 이와 같은 성능을 증가시키기 위해 광학디스크드라이브의 액추에이터는 높은 서보대역폭을 가져서 광학디스크의 진동을 보상할 수 있어야 한다. 하지만 서보대역폭은 액추에이터의 몇몇 유연모드들에 의해 제한되므로 액추에이터 유연모드의 고유진동수를 높이는 설계가 필수적이다. 이 논문은 높은 유연모드 주파수를 갖는 가동 자석형 액추에이터를 제안한다. 일반적으로 가동 자석형 액추에이터는 가동부의 형태가 단순하고, 가동부 자석이 높은 영률을 가지기 때문에 유연모드 주파수를 높이는데 유리하다. 반면 가동부의 질량이 크고 자기 회로의 효율이 좋지 않아 액추에이터의 구동감도가 나쁘다. 이와 같은 단점을 극복하는 방편으로 구동감도를 향상시키기 위해 트랙킹 방향 구동

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을 위한 자기회로가 폐자기회로인 모델을 설계하였다. 추가로 실험계획법을 이용한 자기회로 개선을 통해 구동감도를 향상시켰으며, 유연모드 주파수 또한 렌즈 홀더의 변경을 통해 향상시켰다.

1. Introduction

ODD(optical disk drive) has been developed as a principal storage device of a personal computer with the hard disk drive. CD(compact disk) which is the 1st generation of the optical disk standard was introduced to market as a media for digital music data and its application area was extended to general digital data media for a personal computer. DVD(digital versatile disk) which is the 2nd generation of optical disk standard could store 4.7 GB, around six times the capacity of CD. So it could get a great success in home video market, taking the position of VHS(video home system) which is analog magnetic tape for video data. Nowaday, high definition video contents are being generalized with the spread of HDTV(high definition television) such as PDP(plasma display panel) and LCD(liquid crystal display) TV and DTV (digital television) which is high quality digital broadcasting system. Keeping with this trend, Blu-ray and HD DVD that could store high definition digital video contents was developed and now they are competing for the next generation of optical disk standard. As a media for High definition video data, the next generation of optical disk system should have high data transfer rate and large data capacity. So, there have been many developments in the optical disk drive, for example, increasing the rotational speed of disk for high data transfer rate or improving the recording density of disk for high capacity. To achieve high rotational speed of disk with maintaining the system stability, pickup actuator should have high frequencies of the flexible modes[1~3].

In this paper, moving magnet type actuator which has special EM circuit design is proposed. Generally, moving magnet type actuator has high frequencies of the flexible modes because of simple shaped lens holder and high Young's modulus of moving magnet. But, compared with moving coil type, the driving force is weak because ferromagnetic yoke isn't applicable and the driving sensitivity is low because of large moving mass. However, in the proposed EM circuit, the tracking coils are locate between moving magnets which act as magnets and yokes at same time. So, the magnetic fluxes which cross the tracking coil can be concentrated at the coil without using the ferromagnetic yoke. Designed EM circuit is validated by FE magnetic simulation and the dynamic characteristics of designed actuator are analyzed by FE structural simulation. And then the driving sensitivity is improved through DOE procedures of EM circuit. Lens holder is also improved to increase the flexible mode frequency and modified according to the improved EM circuit.

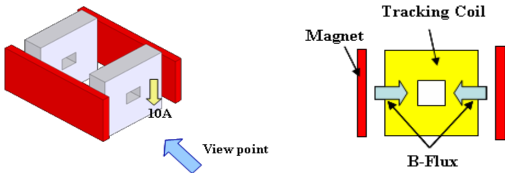
2. The Initial Model

2.1 Design of the Electromagnetic Circuit

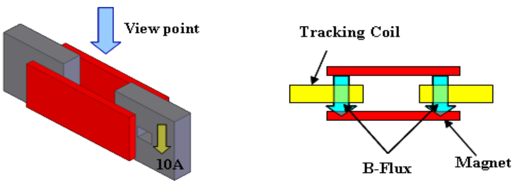
The electromagnetic force which is exerted at a moving electric charge in a magnetic field is a driving force of the voice coil actuator. The EM circuit is designed to maximize the electromagnetic force because the driving sensitivity is dependent on the driving force.

$$\vec{F} = \vec{B} \times \vec{I} L n \tag{1}$$

$\vec{F}$ is the electromagnetic force exerted at a coil in a magnetic field. $\vec{B}$ is the magnetic flux in a coil and $\vec{I}$ is a current of a coil. n is the number of turns of a coil and L is the effective length of

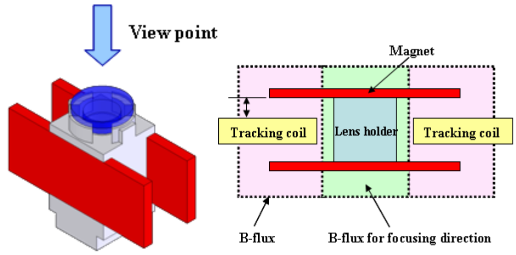


(a) Perpendicular type

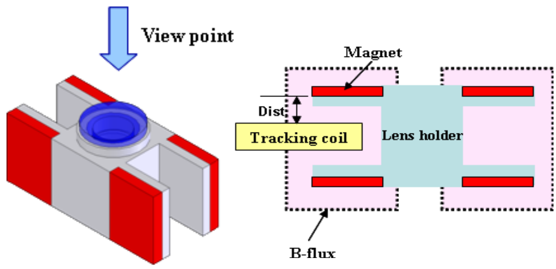


(b) Parallel type

Fig. 1 Conceptual designs of EM circuit



(a) Long type



(b) Split type

Fig. 2 Designs of moving magnet

a coil which is exposed by a magnetic field.

Comparing with moving coil type actuator, moving magnet type actuator has high frequencies of the flexible modes. However, its driving sensitivity is low because the ferromagnetic yoke can't be applied so the magnetic flux, $\vec{B}$, doesn't concentrated on the coil. And the density of a magnet is larger than coil's one thus total moving mass of moving magnet type actuator is much larger than moving coil type actuator. Proposed initial model is focused on making up for these weak points. Conceptual designs of the EM circuit are shown in Fig. 1. Comparing with the perpendicular type, the parallel type has high density of the magnetic flux but effective length is short. For fair competition between two designs, we set the current of each coils same in FE magnetic simulation; nI=10 A. The result shows that the parallel type generates 5.8 mN which is larger than the force of the perpendicular type which is 2.3 mN. Therefore the parallel type is selected. Figure 2 shows another conceptual design of moving magnet. In the long type magnet, lime-green region means unnecessary area in which there're no tracking coils. In the split type design, magnets are shortened and divided into two equal parts so the mass of magnets could be decreased. However, the distance between magnet and tracking coil became larger than long type's one. The distance is very important factor in design procedure of EM circuit and shorter distance is better. Simulations for comparison are also performed in this case and the results show that both designs are almost same with respect to the acceleration sensitivity. However, the long type is better as regards the solidity of structure, thus it is chosen in this paper.

2.2 The Analysis of Dynamic Characteristics of the Initial Model

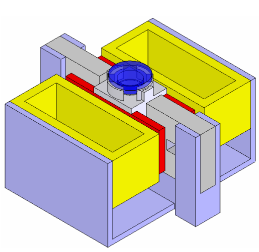
In the design procedure of VCM(voice coil motor) actuator, EM circuit and lens holder are major components and generally they can't be designed independently because they shared many parts each other. In short, designs of EM circuit and lens holder are coupled each other. Moving magnet type actuator has very simple shaped lens holder, thus EM circuit is designed first and then lens holder is fitted to designed EM circuit. Figure 3 shows the initial model:

overall structure, EM circuit, and moving parts and Table 1 comprises dynamic characteristics of the initial model. Dynamic characteristics of the initial model are not satisfied with the expectation, especially AC sensitivity is too low. AC sensitivity is an acceleration performance which depends on the moving mass and the driving force of an actuator. In this case, the driving force was sufficient but the moving mass of the actuator was 462.6 mg which is too large. In the initial model, magnets are occupying a great part of the moving mass. To reduce the moving mass, the magnet size has to be changed and it means that the EM circuit needs to be changed and improved.

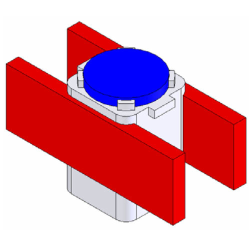
3. Improvement of the Actuator

3.1 Improvement of the EM Circuit

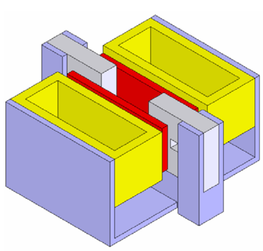
There is a need to improve the initial EM circuit design because the performance of the initial model is too low. At first DOE(design of experiments) is applied to obtain proper design variables of EM circuit. Figure 4 shows 11 variables which are selected for DOE of EM circuit. A, B and C are variables of the moving magnet. D, E, F and G are related with the focusing coil. H, I, J and K are variables of the tracking coil. We performed DOE procedures using a fractional factorial array with 11 variables. The result of DOE shows that there are no interactions between variables of the tracking coil and variables of the focusing coil. In addition, the tracking sensitivity is only affected by variables of the tracking coil, and the focusing sensitivity is so. Based on these facts, design of EM circuit is divided into two parts : focusing EM circuit and tracking EM circuit. 7 variables related with the magnet and the focusing coil are chosen in the focusing EM circuit and DOE procedures using a full factorial array of L128(2^7) are applied. DOE procedures of the tracking EM circuit are same with the focusing one; It uses a full factorial array of L128(2^7) with 7 variables of the magnet and the tracking coil. Interactions between variables



(a) Overall structure



(b) Moving part



(c) EM circuit

Fig. 3 Initial model

Table 1 Dynamic characteristics of initial model

1st reson. frequency	50 Hz		
2nd reson. frequency	Focusing	135.6 kHz	
	Tracking	109.6 kHz	
Moving mass	462.6 mg		
	DC Sen.	AC Sen.	Driving force
Focusing	0.545 mm/V	5.503 G/V	24.951 mN/V
Tracking	0.607 mm/V	6.047 G/V	27.416 mN/V

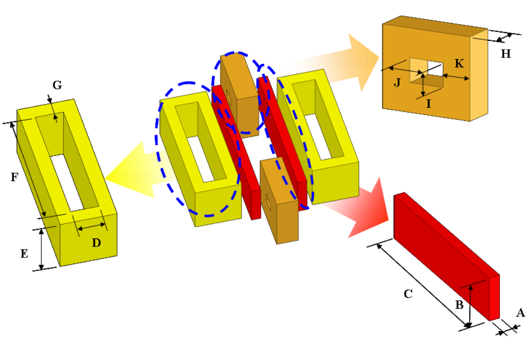
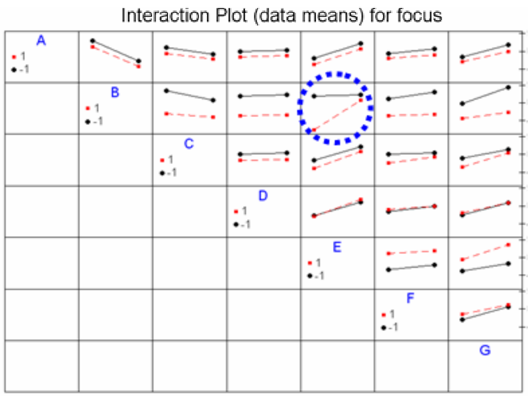


Fig. 4 Design variables

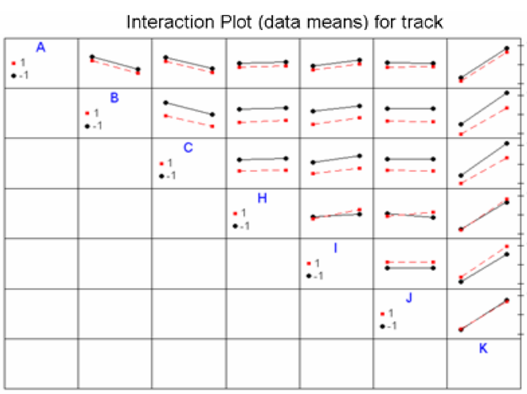
are shown in Fig. 5. There's an obvious interaction between B and E which mean magnet's height and focusing coil's height in the focusing EM circuit. Figure 6 shows the main effect plots. Variable B and variable E have considerable effects on the focusing sensitivity. In order to decouple B and E, E is changed as the ratio of the height of the focusing coil to the height of the magnet like the equation(2).

Table 2 Selected values of design variables of the EM circuit

Variable	A	B	C	D	E
Unit (mm)	0.6	2.4	10.6	1.5	2.88
F	G	H	I	J	K
7.5	1.8	1.4	0.5	1	2



(a) Tracking direction



(b) Focusing direction

Fig. 5 Interaction between variables

$$E^* = E / B \qquad (2)$$

And then DOE procedures which consist only B and E^* are performed again and it is confirmed that there's no the interaction between B and E^*. Table 2 is a summary of selected values of each variables. The value of E is converted from E^* which is 1.2.

3.2 Improvement of the Lens Holder

Many parts of the lens holder is related to EM circuit. Considering the final design of EM circuit, the lens holder is designed. Figure 7 shows the flexible modes of the initial model. The frequencies of the flexible modes of the initial model was satisfactory but the fre-quencies related with the vibration mode of tracking direction is much smaller than the frequency related with the vibration mode of focusing direction. It is shown that the defor-mation of the flexible mode of tracking direction

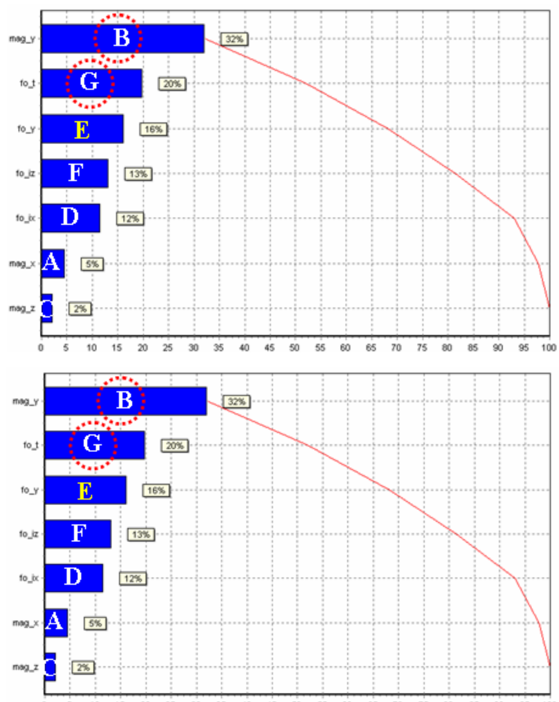
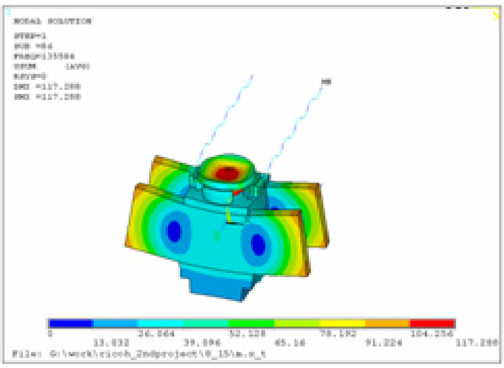


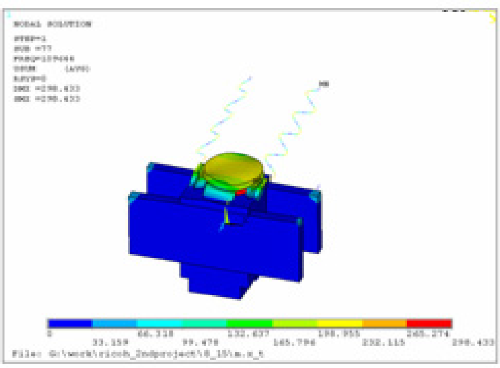
Fig. 6 Main effect plots

is concentrated in the lens upholder. So, it is possible to increase the frequency of the flexible mode of tracking mode by improving the lens upholder. Therefore, the initial model is fitted to the final design of EM circuit and the lens upholder is improved to increase the frequency of the flexible mode of tracking direction. The initial model and the improved model of lens holder are shown in Fig. 8 and the flexible modes of the improved model is shown in Fig. 9. The frequency of the flexible mode of tracking direction is increased from 109.6 kHz to 149 kHz.



135.6 kHz

(a) The flexible mode of focusing direction



109.6 kHz

(b) The flexible mode of tracking direction

Fig. 7 Flexible modes of the initial model

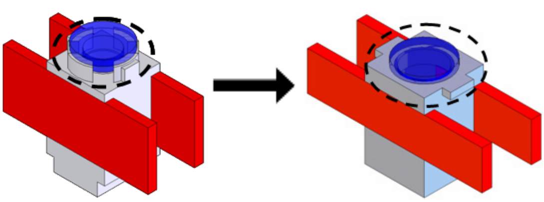
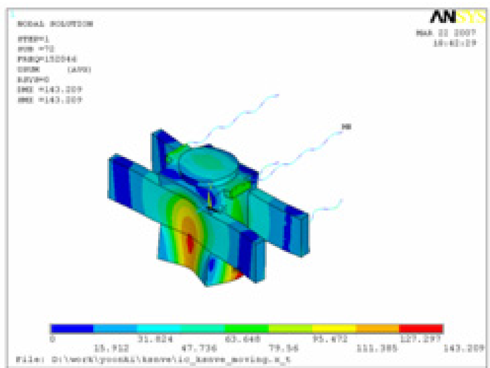


Fig. 8 Improvement of lens holder

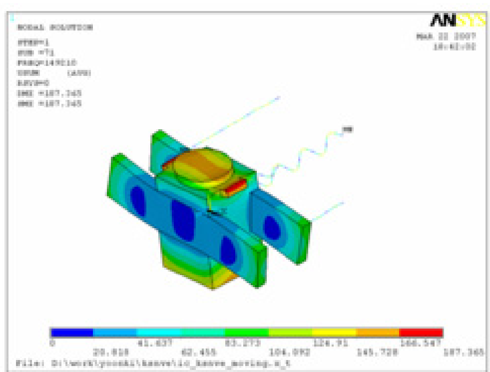
3.3 The Dynamic Characteristics of the Final Model

Through applying the final design of EM circuit and improved design of lens holder, the final model is completed. Figure 10 shows the final model. The dynamic characteristics of the final model is analyzed by FE simulation and summarized in Table 3. Comparing with the initial model, the driving forces are decreased. However the reduction of the moving mass is



152 kHz

(a) The flexible mode of focusing direction



149 kHz

(b) The flexible mode of tracking direction

Fig. 9 Flexible modes of the improved model

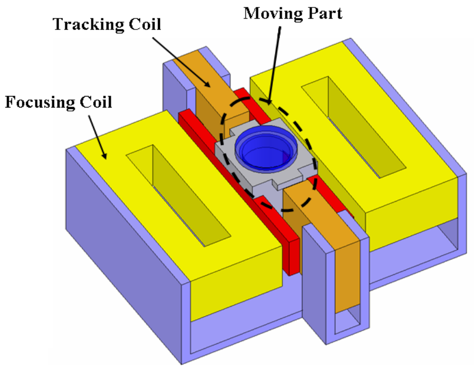


Fig. 10 The final model

Table 3 Dynamic characteristics of the final model

1st Reson. frequency	50 Hz		
2nd Reson. frequency	Focusing	152 kHz	
Tracking	149 kHz		
Total mass	292 mg		
	DC Sen.	AC Sen.	Driving force
Focusing	0.788 mm/V	7.9 G/V	22.716 mN/V

more than the reduction of the driving forces, and therefore the acceleration performance of the actuator could be increased. And it is shown that the frequencies of the flexible modes are also increased.

4. Conclusions

In this paper, moving magnet type actuator which has high frequencies of the flexible modes is suggested. To improve the driving sensitivity of the actuator, EM circuit is improved by using DOE procedure. DOE procedures of EM circuit is divided into two parts: the focusing EM circuit and the tracking EM circuit. And they are performed independently. By DOE procedure, the driving sensitivity of the actuator is increased. The lens holder is also improved to have high frequencies of the flexible modes and fitted to the final design of EM circuit. At last, the final model is completed and its dynamic characteristics are analyzed by FE simulation. The simulation result shows that the final model of the actuator has good driving performance and high frequencies of the flexible modes.

Acknowledgements

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