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전자기력을 이용한 대변위 구동 2축 스캐닝 미러의 설계

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Design of a large deflection 2 DOF scanning mirror using an electromagnetic force

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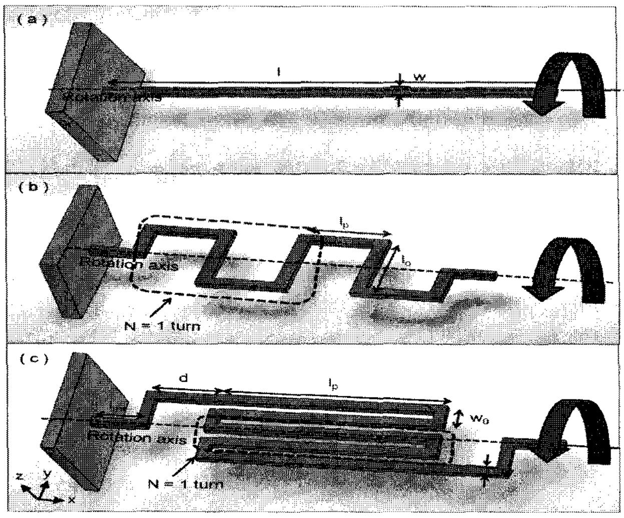
Abstract - In this paper, we present the design of an electromagnetic scanning mirror with rotated serpentine springs. We considered three types of torsional springs: simple beam springs (SBS), classic serpentine springs (CSS), and rotated serpentine springs (RSS). The analysis was done for an electrical resistance, differences in the mode-frequency, and resonances regarding to spring thickness. Electromagnetic coils under the mirror plate were also analyzed for power consumption and the mechanical deflection. From the analysis result, RSS and electromagnetic coils were designed for the silicon scanning mirror.

1. Introduction

Since 1980s, scanning mirrors using MEMS technology have been studied and developed intensively in the applications including imaging system, scanning device, high power laser systems. Each application requires own specifications of a scanning mirror so that proper mechanical flexures should be selected for the specific applications.

In this paper, the design procedure of an electromagnetic scanning mirror is presented. It consists of the design of torsion spring and the optimization of electromagnetic coils. Since the target application is a laser display, the design starts with the specifications of the application.

Many mirror applications usually adopted the SBS because of simplicity [1]. In our application, however, the mirror plate is relatively large and heavy so that SBS must be lengthen to achieve the same amount of torsion angle. The long SBS have a few drawbacks such as low stiffness ratio and large occupied area. Therefore, to design a spring for our scanning mirror, we analyze and compare SBS, CSS, and RSS each other. Finally, we analyze the effect of a width of metal coils for reducing power consumption.



<Fig. 1> Structure view of three spring types. (a) beam spring (b) classic serpentine spring (c) rotated serpentine spring

2. Design of torsional spring

Three types of springs are compared with each other for electrical resistance, spring thickness effects on resonant frequencies, and a ratio between the first and the second frequency modes. Structures of three types of springs are as shown in Fig.1. Giuseppe Barillaro *et al.* derived spring stiffness equations using beam approximations [2]. Unfortunately our design has high w-t and w-l_p ratio so that the beam approximations cause errors about 10 percent compared with FEM simulation. Therefore, FEM simulation is used for resonant frequency estimation instead of beam approximations. Table 1 shows simulated model parameter and result of resonance frequency. Model parameters are based on the specification of the application. First, the size of mirror plates is 2.5 × 2.5 mm^2 to be used with 2.0 mm diameter laser spot. Second, a torsional resonance frequency must be over than 400 Hz since the mirror in our application actuates in a static mode with lower than 300 Hz. Finally a rotating angle of the scanning mirror must be up to 5° to display target area. The device thickness t and spring width w were initially fixed to 50 ㎛. Target frequency of simulation is 400 Hz ± 5 % and the mirror plate which is connected with springs is assumed 4.8 × 4.8 mm^2. The inertia of the mirror plate is the same as that of the mirror with frame.

<Table 1> Simulated parameters and result

FEM simulation		SBS	CSS		RSS		
spring parameters							
turns			1	5	1	5	10
length	l_p	4250	100	100	600	200	90
(㎛)	l_o		1200	350	70	70	70
result							
f_θ (Hz)		401	408	405	393	414	413

2.1 Metal coil resistance

Metal (Cu-Ni-Cr) coils for the electrostatic actuation are connected via springs so that a long spring length results in increased electrical resistance. As shown in Table 2 the resistance of RSS with one turn is not only the lowest among all models at the same spring constant, but also about 30 % lower than classic serpentine springs. The RSS have better resistance feature for the scanning mirror than the others.

2.2 Resonant frequency ratio

The first resonance mode of mirror is rotational and the second mode is vertical direction movement. Therefore, if two modal frequencies are close, unwanted actuating will easily occur. For forward stable rotations, it is important for a mirror to maintain the large separation between the first and the second frequency modes. Table 2 shows the first and the second frequency ratio ; f_Θ and f_z, for three types of springs and the frequency ratio is used as an index of stablilty. The high frequency ratio means high stablilty. The RSS has about 40 % higher ratio than CSS and about 250 % higher than SBS.

<Table 2> Summarized spring analysis.

	SBS	CSS		RSS		
N turns		1	5	1	5	10
Analysis result						
Resistance (Ω)	3.6	4.6	4.7	3.2	3.8	4.6
f_2/f_θ	1.3	3.4	3.2	5.3	4.7	2.9
$\frac{frequency\ error}{thickness\ error}$ (%/㎛) (Range of the thickness : 40 ~ 60㎛)	2.0	3.8	3.5	2.1	2.6	3.1
lateral length (㎛)				860	460	350

2.3 Spring thickness effect on resonant frequencies

Another advantage of the RSS is a low dependency of resonance frequency on spring thickness. Thickness and width have errors during fabrication due to footing effect in deep reactive ion etching or under cut. The spring width error is smaller than the thickness error so that we only consider the thickness errors. Five cases, ±5 , ±10 percent of 50 ㎛ are simulated and the relative error is calculated. Table 2 also shows a frequency error divided by spring thickness error. As for the frequency error per thickness of spring error, RSS are better than classic serpentine springs by 35 %

2.4 Designed parameters of springs

So far, various properties depending on the spring types are investigated. According to the simulation result, it is proved that the RSS has outstanding features such as low electrical resistance, less dependency of resonance frequency on the spring thickness and enough modal-frequency separation. Additionally, since serpentine springs have lower torsion stress than SBS, the RSS is determined to be fit for our large scanning mirror.

Therefore, we choose an RSS with 5 turns for acceptable resistance and lateral length. The main parameter of N and lp are designed to be 5 and 200 ㎛, respectively. This spring is adopted for frame spring.

3. Design of electromagnetic coil

Metal in combination of Cu, Ni, and Cr is deposited under the mirror plate to form electromagnetic coils. The specific resistance ρ and thickness t of deposited metal are measured to be 0.0036 Ω ㎛ and 0.85 ㎛, respectively in test experiments. The gap between the metal coils are initially fixed 10 ㎛ to prevent from leakage current and misalignment.

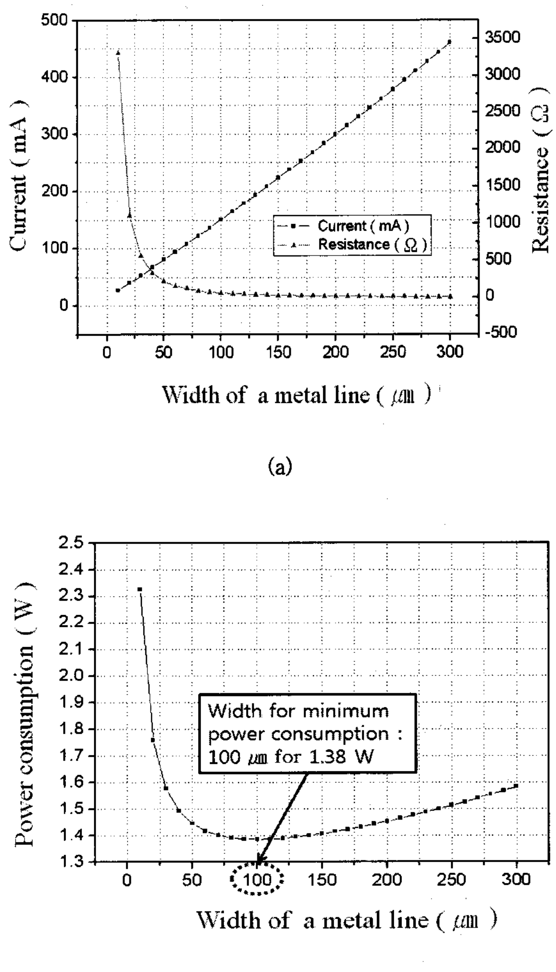
The power consumption P for a certain torsional angle is given by the following equations,

$$P = i^2 R = \left| \frac{k_\theta \Theta}{\sum_k (\overrightarrow{L_k} \times \overrightarrow{B_k}) \times \overrightarrow{r_k}} \right|^2 \left(\rho \frac{1}{wt} \sum_k L_k\right)$$

, where L and Θ represent the length of the metal coils and torsional angle, respectively. And torsional stiffness k_θ is calculated from the resonance frequency which is middle of the first and second mode of the frame spring.

From the equation, the P is determined by the width of metal lines w because a current i and a resistance R are the function of w.

In Fig. 2 , R, i, and P are plotted against w, a minimum P appears when w is 100 ㎛. Therefore, w is designed to be 100 ㎛ and R i, and P are calculated 61 Ω, 151 mA and 1.38 W, respectively.



<Fig. 2> The effect of coil width on (a) resistance of the metal lines and required current for 5 degrees of torsion, (b) power consumption.

4. Conclusion

In this paper, we showed an approach to design the torsional spring of an electromagnetically-actuated two DOF scanning mirror. SBS, CSS, and RSS were analyzed mainly by FEM simulation. It was found that the RSS have various advantages for the scanning mirror such as resistance, small dependencies on spring thickness, and large ratio between the first and the second resonance frequencies. Also we analyzed and optimized the effect of the coil width on the power consumption. Based on the analysis result, we designed the RSS and the electromagnetic coil of the large scanning mirror.

[Reference]

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