Development of Compact Auto Focus Actuator for Camera Phone by Applying New Electromagnetic Configuration

Chung Myung-Jin*
Department of Mechatronics Engineering, Korea Polytechnic University, 2121, Jeongwang-Dong, Siheung-Si, Gyeonggi-Do 429-450, Korea
Son Sung-Yong
Department of Electric and Information Engineering, Kyungwon University, San 65 Bokjeong-Dong, Sujeong-Gu, Seongnam-Si, Gyeonggi-Do 461-701, Korea

In this paper, auto focus actuator, which is used to move a lens module in the mobile phone having a camera module, is developed. Camera module containing auto focus actuator requires to minimize total size because of characteristics of the application area such as mobile phone, digital camera, and personal digital assistant. There are stepping motor, voice coil motor, and piezoelectric motor as auto focus actuator. In this paper, voice coil motor having new electromagnetic configuration is proposed. And actuator using proposed voice coil motor is developed by optimal design method using magnetic circuit analysis. The sectional area of the developed actuator is reduced to 32.4% compared with actuator using general electromagnetic configuration. From the performance test, the developed actuator has moving stroke of 0.64 mm for 2.1 volt, hysteresis of 40 μm, full stroke current of 54 mA, and unit step motion of 3 μm.

Key Words : Auto Focus Actuator, Camera Phone, Camera Module, Magnetic Circuit Analysis, Optimal Design

Nomenclature

b_{arm} : Arm width of the plate spring
B_g : Magnetic flux density at the air gap
B_r : Remanence flux density of the magnet
d_{coil} : Diameter of the coil
E : Young's modulus of the plate spring
F_{emag} : Electromagnetic force
F_{min} : Minimum electromagnetic force
g : Air gap
h_{coil} : Coil winding thickness
h_{mag} : Thickness of the magnet
i : Current flow
i_{max} : Maximum current
k : Spring constant of the plate spring
k_{ml} : Magnet leakage factor
L_{arm} : Arm length of the plate spring
l_e : Effective length of the coil facing with magnet
n : Coil winding number
R : Resistance of the coil
r_b : Inner diameter of the barrel
t : Thickness of the plate spring
t_b : Thickness of the barrel
T_c : Temperature of the coil
t_{yoke} : Thickness of the yoke
V : Applied voltage
w_{coil} : Coil winding width
α_m : Magnet fraction
δ : Moving stroke
μ_r : Recoil permeability of the magnet
ρ : Resistivity of the coil

* Corresponding Author,
E-mail : mjchung@kpu.ac.kr
TEL : +82-31-496-8251; **FAX** : +82-31-496-8259
Department of Mechatronics Engineering, Korea Polytechnic University, 2121, Jeongwang-Dong, Siheung-Si, Gyeonggi-Do 429-450, Korea. (Manuscript **Received** March 23, 2006; **Revised** August 30, 2006)

1. Introduction

The mobile phone having a camera module is

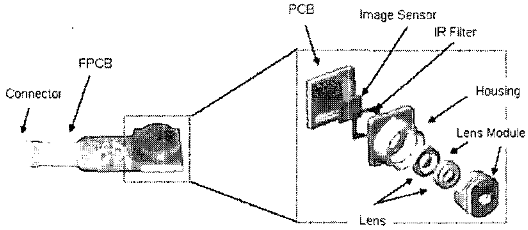


Fig. 1 Configuration of the camera module

called camera phone. Camera module consists of image sensor, lens module, infra red (IR) filter, housing, printed circuit board (PCB), flexible PCB (FPCB), and connector as showed in the Fig. 1 (Lee, 2004).

Recently, in the market of the camera phone, number of pixels in the image sensor has been increased for acquisition of the market share. Camera phone using high pixel image sensor having above 2.0 mega pixel required to have an additional function such as optical zoom and auto focus. Because these functions need the actuator for moving lens module, camera phone becomes bulky. Camera module containing auto focus actuator requires to minimize total size because it is inserted in the mobile phone. Therefore, study for minimization of the actuator using for optical zoom and auto focus has been conducted by the many researchers (Kim, 2001 ;.Choi, 1999).

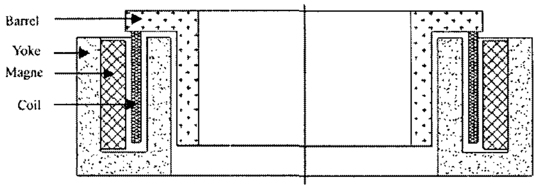
In this work, auto focus actuator, which is used to move a lens module in the mobile phone having a camera module, is developed. There are stepping motor, voice coil motor, and piezoelectric motor as auto focus actuator. A voice coil motor having new electromagnetic configuration is proposed. And actuator using proposed voice coil motor is developed by optimal design method using magnetic circuit analysis. Camera module having the developed actuator, image sensor, and electric circuit is attached to the image processing system. Performance test is conducted to verify the developed actuator.

2. Comparison of Electromagnetic Configuration

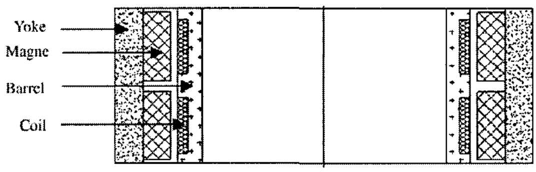
The driving methods such as stepping motor, voice coil motor, and piezoelectric motor are used usually as an auto focus actuator in the camera phone. Among these driving methods, stepping motor has disadvantage of large size and piezoelectric motor has disadvantage of low repeatability (Kim, 2005). On the other hand, voice coil motor has advantage of small size and high repeatability, so selected as the actuator for camera phone. Table 1 lists the advantages and disadvantages of the each driving method (Chung, 2005).

Table 1 Comparison of the driving method using in the auto focus actuator

	Stepping motor	Piezoelectric motor	Voice coil motor
Advantage	Shock stability	Power loss	Size
Disadvantage	Size	Repeatability	Power loss



(a) General voice coil motor



(b) Proposed voice coil motor

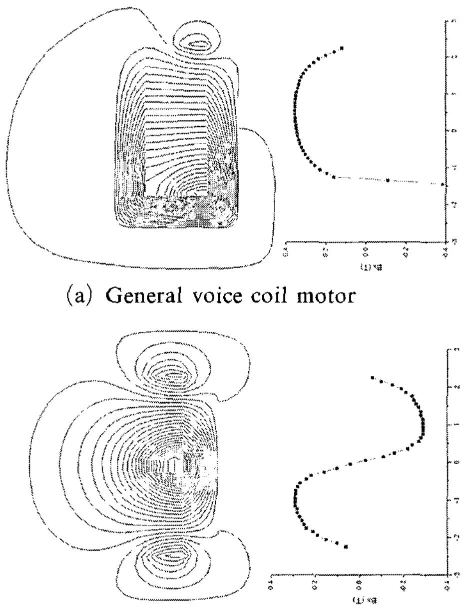
Fig. 2 Electromagnetic configuration using in the camera module

2.1 Electromagnetic configuration

In general, voice coil motor for auto focus actuator has electromagnetic configuration as shown in Fig. 2(a); winding coil is fixed in the barrel having lens module, and magnet attached at the yoke is faced with the each winding coil. Whereas proposed electromagnetic configuration is that winding coil is wound in the barrel with different winding direction. And magnet fixed at the yoke has different magnetization direction to face with winding coil as shown in Fig. 2(b).

2.2 Comparison of magnetic flux density

Finite element analysis (FEA) is used to cal-



(a) General voice coil motor

(b) Proposed voice coil motor

Fig. 3 Cross section model and y-axis (optical axis) magnetic flux density distribution

Table 2 Average magnetic flux density and sectional area of the each electromagnetic configuration

	General configuration	Proposed configuration	Unit
Magnetic flux density	0.312	0.262	Tesla
Sectional area	167.4	113.1	mm^2

culate magnetic field distribution of magnetic circuit configuration, and is used to compare with two magnetic circuit efficiencies. Figure 3 shows the cross section model used in FEA and y-axis (optical axis) magnetic flux density distribution at the center of the winding coil.

In the Fig. 3(b), direction of the magnetic flux density is reversed according to the direction of the magnetization. Average value of the flux density and sectional area over the moving range of the winding coil is listed in the Table 2. The average value of the flux density from the proposed electromagnetic configuration is reduced in the rate of 16.0% compared with general electromagnetic configuration. But, the sectional area is reduced in the rate of 32.4%. From this data, proposed electromagnetic configuration can be used as driving method for auto focus actuator, because reduction effect of the sectional area is bigger than the reduction effect of the performance.

3. Design of Auto Focus Actuator

3.1 Actuator requirement

In the camera module, objective lens moving along the optical axis to focus objective image at the image sensor is assembled in the housing with focal point of long distance. There are requirements in the actuator design ; moving stroke over 0.4 mm which depend on the optical path, minimum hysteresis along the moving stroke, full stroke current under 100 mA, and unit step motion under 10 μm.

3.2 Design method

Design of auto focus actuator consists of electromagnetic circuit design and mechanism design. Electromagnetic circuit design is conducted using the mathematical modeling by permeance method and optimal design procedure (Hanselman, 1994 ; Chung, 2003). In the optimal design procedure, objective function is used as the minimum sectional area in the condition of the force requirement, because actuator of small size is required to insert in the camera module.

The sectional area of the actuator is given by

$$A_{act}=\pi r^2=\pi(r_b+t_b+h_{coil}+g+h_{mag}+t_{yoke})^2 \quad (1)$$

where, r_b is an inner diameter of the barrel, t_b is a thickness of the barrel, h_{coil} is a coil winding thickness, g is an air gap, h_{mag} is a thickness of the magnet, t_{yoke} is a thickness of the yoke, respectively.

The electromagnetic force produced by magnet flux and current flowing through the coil is given by

$$F_{emag}=nB_g i l_e \quad (2)$$

where, n is a coil winding number, B_g is a magnetic flux density at the air gap, i is a current flow, and l_e is an effective length of coil facing with magnet, respectively.

The coil winding number related with coil diameter and winding area is given by

$$n=Int\left(\frac{w_{coil}}{d_{coil}}\right)Int\left[\frac{h_{coil}+\left(\frac{\sqrt{3}}{2}-1\right)d_{coil}}{\frac{\sqrt{3}}{2}d_{coil}}\right] \quad (3)$$

where, w_{coil} is a coil winding width, and d_{coil} is a diameter of the coil.

Magnetic flux density is calculated by using the permeance method (Hanselman, 1994; Chung, 2002), and related with magnet, yoke, and air gap as given by

$$B_g=\frac{1}{1+\frac{2\mu_r\alpha_m k_{ml} g}{(1+\alpha_m)h_{mag}}}B_r \quad (4)$$

where, μ_r is a recoil permeability of the magnet, α_m is a magnet fraction, and k_{ml} is a magnet leakage factor, B_r is a remanence flux density of the magnet.

Current related with coil winding length and coil diameter is given by

$$i=\frac{V}{R}=\frac{V\pi d_{coil}^2}{4\rho n l_e} \quad (5)$$

where, V is an applied voltage, R is a resistance of the coil, ρ is a resistivity of the coil, respectively.

To design the actuator having the minimum sectional area in the condition of force requirement, optimal design method is used. The SQP is used for optimal design of actuator. This method uses an iterative procedure, and generates a quadratic programming sub-problem at each iteration, and updates the estimate, which is the Hessian of Lagrangian.

From Eqs. (1) ~ (5), the electromagnetic force is related with electric and geometric parameters. In the constraint of the force requirement, these parameters affecting the sectional area are selected as design variables, and the other parameters are selected as fixed variables.

The optimal design method aims to minimize the sectional area of the auto focus actuator. The cost function is given by

$$J(x)=A_{act} \quad (6)$$

The design variables are selected such as coil diameter, coil winding thickness, air gap, magnet thickness, and yoke thickness. And fixed variables are applied voltage, coil winding width, yoke width, and magnet width, inner diameter and thickness of the barrel.

The constraints are the minimum electromagnetic force F_{min}, maximum current i_{max}, and temperature of coil T_c. The constraint conditions are given by

$$g_1(x)=G_1-F_{min}\leq 0 \quad (7)$$

$$g_2(x)=G_2-i_{max}\leq 0 \quad (8)$$

$$g_3(x)=T_c-G_3\leq 0 \quad (9)$$

where, $G_1=0.1$ (N), $G_2=100$ (mA), $G_3=80$ (℃).

We set initial value of design variables as the middle of bounded value, and convergence tolerance as 0.01%.

Table 3 lists the values of optimized design variables of the actuator. Air gap and yoke thickness are bounded to the low limit value.

In mechanism design, the plate spring dimension is determined by using Eqs. (10) and (11)

Table 3 Optimized values of design variables

Parameter	Value	Unit
Coil diameter	0.06	mm
Coil winding thickness	0.3	mm
Air gap	0.25*	mm
Magnet thickness	0.8	mm
Yoke thickness	0.8*	mm

* : Active bounded

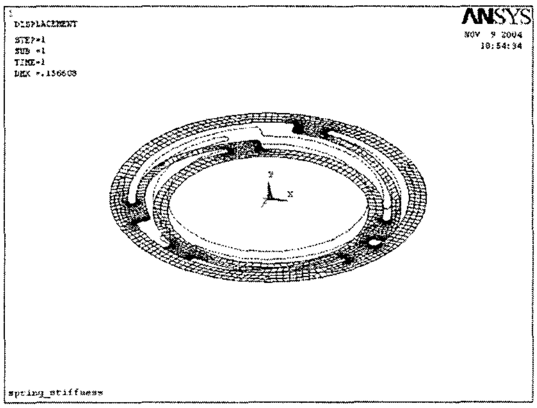


Fig. 4 Static deflection of the plate spring obtained by finite element analysis

and verified by finite element analysis as showed in the Fig. 4.

$$\delta=\frac{F}{k} \tag{10}$$

Where, δ is a moving stroke, k is a spring constant of plate spring.

$$k=\frac{Eb_{arm}t^3}{4L_{arm}^3} \tag{11}$$

where, E is an Young's modulus, b_{arm} is an arm width, t is a thickness, and L_{arm} is an arm length of the plate spring, respectively.

4. Experimental Setup and Results

4.1 Experimental setup

Experimental setup for performance test is showed in the Fig. 5. Laser doppler vibrometer (Polytec OFV512/OFV3001) is used to measure the displacement of the lens module and current probe (TM502A) is used to measure the current flow through the winding coil. Driving signal is applied by function generator.

4.2 Performance test

4.2.1 Moving stroke and hysteresis

Maximum moving stroke and hysteresis are measured from the displacement of the lens module according to the driving voltage. Maximum moving stroke is measured to 0.64 mm for 2.1 driving voltage, and hysteresis is measured to 40 μm for upward and downward motion as showed in the Fig. 6. Current flow according to the driving voltage is measured 54 mA at the 0.57 mm stroke for 1.8 driving voltage in the condition of current probe having the sensitivity of 20 mA/V.

4.2.2 Dynamic response

Dynamic response is measured by applying the 1.5 driving voltage (CH 1) in the winding coil, where the moving stroke is 0.48 mm (CH 2) as showed in the Fig. 7. Settling time for 0.48 mm stroke is measured to 20 msec (CH 2) under.

4.2.3 Unit step motion

Unit step motion is measured by applying the minimum driving signal to the winding coil. Measured unit step motion is 3 μm under the devel-

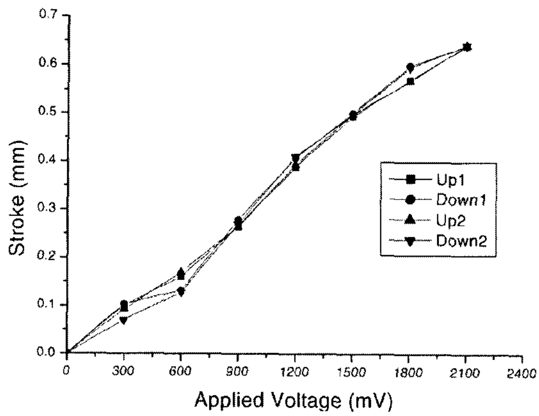


Fig. 6 Moving stroke and hysteresis according to the driving voltage

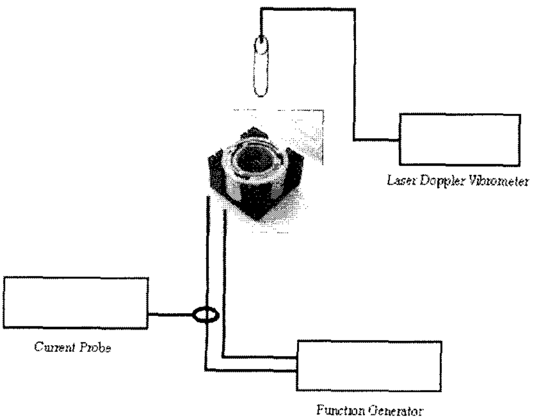


Fig. 5 Developed actuator and experimental setup

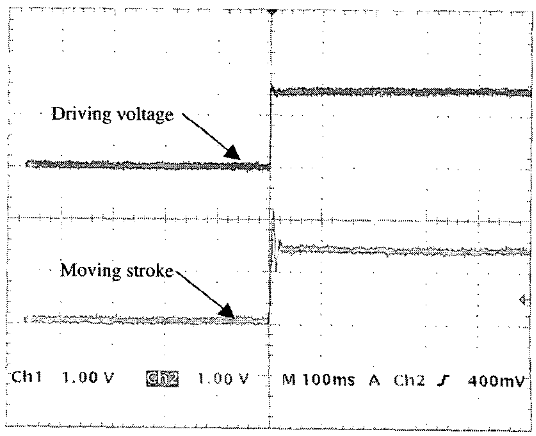


Fig. 7 Dynamic response for 1.5 driving voltage

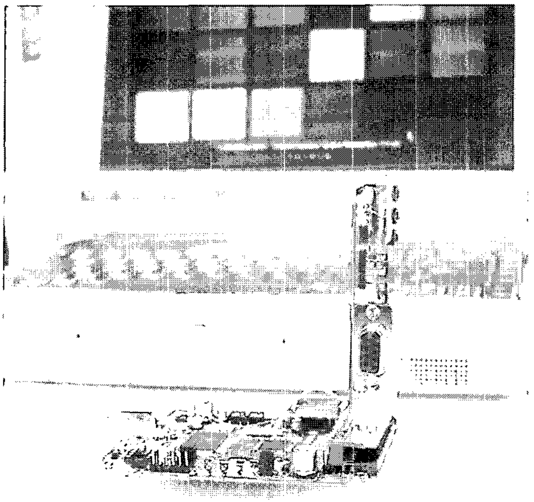
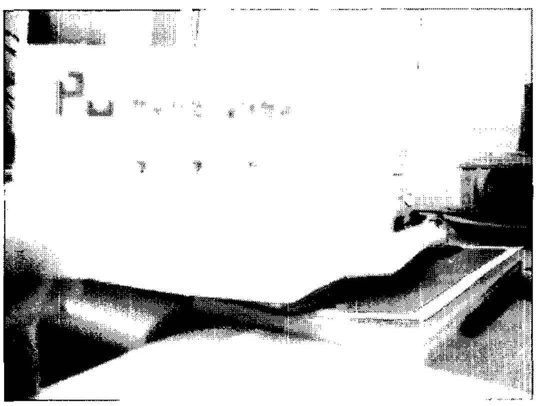


Fig. 8 Experimental setup consisted with developed camera module and image processing system



(a) Deactivated auto focus function

(b) Activated auto focus function

Fig. 9 Captured image according to auto focus function

oped circuit using the 8 bit digital analog converter.

4.2.4 Auto focus function

Camera module assembled with the developed actuator, image sensor, and electric circuit is attached to the image processing system. Experimental setup for testing of auto focus function is showed in the Fig. 8. Figure 9 shows the captured images according to the activation and deactivation of the auto focus function, respectively. From the Fig. 9, distinct image can be achieved by the activation of the auto focus function.

5. Conclusions

In this work, auto focus actuator which is used to move a lens module in the mobile phone having a camera module is developed. The sectional area of the developed actuator is reduced in the rate of 32.4% in the condition of the 16.0% reduction of the average magnetic flux density compared with general electromagnetic configuration by using the proposed electromagnetic configuration.

Also, the developed actuator has the performance such as maximum moving stroke of 0.64 mm, hysteresis of 40 μm, maximum current flow of 54 mA, unit step motion of 3 μm, respectively. Camera module having the developed actuator, image sensor, and electric circuit is attached to the image processing system. Distinct image can be achieved by the activation of the auto focus function.

References

Choi, I. M., Kim, S. H., Kwak, Y. K. and Choi, K. B., 1999, "A New Optical Disk Actuator Combining Coarse and Precise Fine Motion in a Single Actuation System," *KSME*, Vol. 23, No. 3.

Chung, M. J. and Gweon, D. G., 2003, "Optimal Design and Development of Elecrtomagnetic Linear Actuator for Mass Flow Controller," *KSME International Journal*, Vol. 17, No. 1.

Chung, M. J. and Gweon, D. G., 2002, "Modeling of the Amrture Slotting Effect in the Magnetic Field Distribution of a Linear Permanent

Magnet Motor," *Electrical Engineering*, Vol. 84.

Chung, M. J., 2005, "Actuators for Optical Zoom and Auto-Focus in the Camera Phone," *Electronic parts and components*, No. 3.

Hanselman, D. C., 1994, *Brushless Permanent-Magnet Motor Design*, McGraw-Hill, New York.

Kim, H. S., In, C. H., Yoon, G. H. and Kim, J. W., 2005, "Design and Fabrication of a Micro PZT Cantilever Array Actuator for Applications in Fluidic Systems," *Journal of Mechanical Science and Technology*, Vol. 19, No. 8.

Kim, K. H., Lee, M. G. and Gweon, D. G., 2001, "The Design and Performance Test of Tracking Actuator for NFR System," *KSPE*, Vol. 18, No. 8.

Lee, S. J., 2004, *Industry of Camera module*, Industry outlook.