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Fabrication and characteristics of impact type ultrasonic motor

Kee-Joe Lim[a,*], Jong-Sub Lee[b], Seong-Hee Park[a], Seong-Hwa Kang[c], Hyun-Hoo Kim[d]

[a] *School of Electrical and Computer Engineering, Chungbuk National University, Cheongju, Chungbuk 361-763, Korea*

[b] *Department of T&R Support, SMBA, Suwon, Kyunggi, Korea*

[c] *Department of Fire Prevention and Safety Engineering, Chungcheong University, Gangnae, Chungbuk, Korea*

[d] *Department of Electronic and Computer Engineering, Doowon College, Ansung, Kyeonggi 456-890, Korea*

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Abstract

The design and characteristics of novel ultrasonic motor, which is applicable to automatic focus and optical zoom operation of lens system for cellular phone and PDA, are investigated. The motor has a small-scale size and simple structure, which is composed of tungsten plate, multi-layers piezoelectric ceramic block and carbon fiber rod. As the experimental results, the motor can move linearly in forward and backward movement with changing waveform of applied voltage. The testing motor of 2 mm diameter and 7.9 mm length exhibits maximum speed of 6 mm/s and consumption power of 0.1 W, driven at saw tooth wave of 10 V_{p-p}, frequency of 61 kHz, and mechanical load of 2 g. Considering its performance such as low power consumption, low operating voltage and simple structure, the proposed motor may be applicable to automatic focus and optical zoom operation of lens system in the mobile instruments.

Keywords: Actuators; PZT; Piezoelectric properties; Tape casting

1. Introduction

Recently, the function of a digital camera in PDA and cellular phone is necessarily equipped by the convergence of information telecommunication technology and multimedia technology. The number of pixel in camera phone is dramatically increased, which is nearly at same level with the conventional digital camera. However, the function of automatic focus (AF) and optical zoom in camera phone is not yet sufficient, comparing with the digital camera. AF and optical zoom in camera function are necessary because the quality of photograph depends on them. A miniaturized actuator is needed to operate AF and/or optical zoom function, which is limited in size for mounting in mobile phone.[1] The actuator for optical zoom is mostly stepping motor or DC motor, but their problem is in size and performances. Minimum size of stepping motor is 4 mm in diameter and its thrust or torque is not yet sufficient to move the lens. Also, the conventional electromagnetic motor has to use the reduction gear to decrease its fast speed and is hard to control precisely due to its backlash. The ultrasonic motor (USM) can overcome these problems, which is occurred in electromagnetic motor. Compared to typical electromagnetic motors, USM has various advantages.[2] It may be manufactured in wide range of sizes, from a few micrometers to several centimeters in motor diameter. No gears are necessary to reduce the speed of rotation. It is solid-state in nature, and the component parts such as windings, magnets, or brushes are not necessary. Highly accurate speed and position control of USM are relatively ease under feedback control systems, unlike electromagnetic motors that require sensors and controllers to ensure accuracy in position control. It is capable of delivering high torque for its size, which is excellent for low speed applications. With low rotor inertia and large torque, it is exceptionally operating with a response time as short as a few milliseconds. Finally, it possesses inherent braking action without power, making it useful for robot and step motor applications. Various types of ultrasonic motor have been proposed for A/F and optical zooming usage in the mobile phones and PDAs.[3,4] However, practical applications of these motors are

* Corresponding author.
E-mail address: kjlim@chungbuk.ac.kr (K.-J. Lim).

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somewhat limited up to the present due to complicated structure, high power consumption, high operating voltage, high manufacturing cost, and etc.[2,5] USM is newly designed for A/F and optical zoom function of camera phone. Based on simulation results of vibration mode of the motor, a prototype USM is fabricated and its performances will be measured and discussed.

2. Structure of impact ultrasonic motor and its operation

In order to apply an ultrasonic motor to an actuator for A/F and optical zoom operation of lens system in PDAs and cellular phones, the motor is desired the following performances such as low power consumption, low operating voltage, high resolution in linear position control, quick response, small in size, simple structure, and etc.[2,4] The impact ultrasonic motor for application to the camera module of cellular phone proposed in this paper is shown as Fig. 1. The structure of ultrasonic motor is that the elastic disk attaches on piezoelectric ceramics block and the cylindrical carbon fiber rod locates on them. The rod is inserted into lens holder and fixed by plate spring. The elastic body is disk-type tungsten of 2 mm in diameter and 1.4 mm thickness, and the piezoelectric block of 13 layers is 2 mm × 2 mm × 1 mm ($L \times W \times T$). The size of carbon rod is 1.6 mm diameter and 5.5 mm length. Since the number of components is reduced and fabrication process is much simplified, the manufacturing cost is decreased remarkably.

As well-known, the voltage is applied to piezoelectric block in the same direction with the polarization, the block extends in thickness. It restores to the original state without the voltage. The rod of the motor can also move forward or restore by following the movement of the piezoelectric ceramic block. The lens holder with carbon fiber rod is fixed by spring as the previous mentioned. The forward and backward motion of lens holder is realized by the movement of the rod and the law of inertia among the rod, lens holder and plate spring with voltage waveform control. Therefore, the automatic focus control is carried out the motion of lens holder as shown in Fig. 2(a). The elastics in the bottom side of ultrasonic motor leave out in Fig. 2(a) and it is considered that the lower part of piezoelectrics is fixed. Fig. 2(b) shows the wave pattern of the applied voltage. The positive voltage means the case of applied voltage under the same direction with polarization. The period (1) in Fig. 2(a) corresponds to point (1) in Fig. 2(b), and then the voltage is zero as an initial state. As the voltage increases slightly like a duration of (1) → (2) in Fig. 2(b), the piezoelectric block extends to thickness direction as shown in Fig. 2(a) (2), and the lens holder moves from d_1 to d_2. When the voltage goes to zero abruptly as shown in Fig. 2(b) (2) → (3), the piezoelectrics contracts to the original state. Therefore, the rod slips backward only by the law of inertia, and the lens holder stays at position d_2. Another reason for this slip motion of rod is due to the decrease of Coulomb friction force. As the voltage increases in the duration of Fig. 2(b) (3) → (4), the lens holder moves to d_3 in Fig. 2(a) with the extension of piezoelectric block. The lens holder goes forward continually by the applied pulse of saw tooth waveform sequentially. When the voltage increases abruptly in Fig. 2(b) (5) → (6), the rod moves forward rapidly by the fast extension of piezoelectrics. However, the lens holder is fixed at d_3 as shown in Fig. 2(a) (6) similar to the mentioned process in Fig. 2(b) (2) → (3) due to law of inertia. On the other hand, as the voltage decreases slowly in Fig. 2(b) (6) → (7), the piezo-

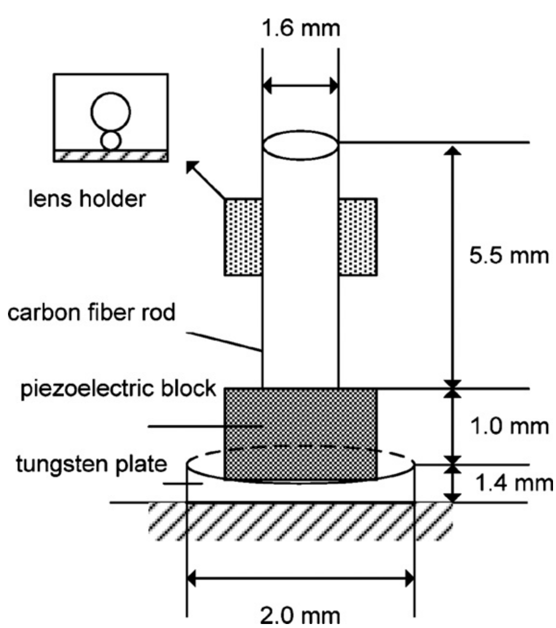

Fig. 1. Structure of impact ultrasonic motor.

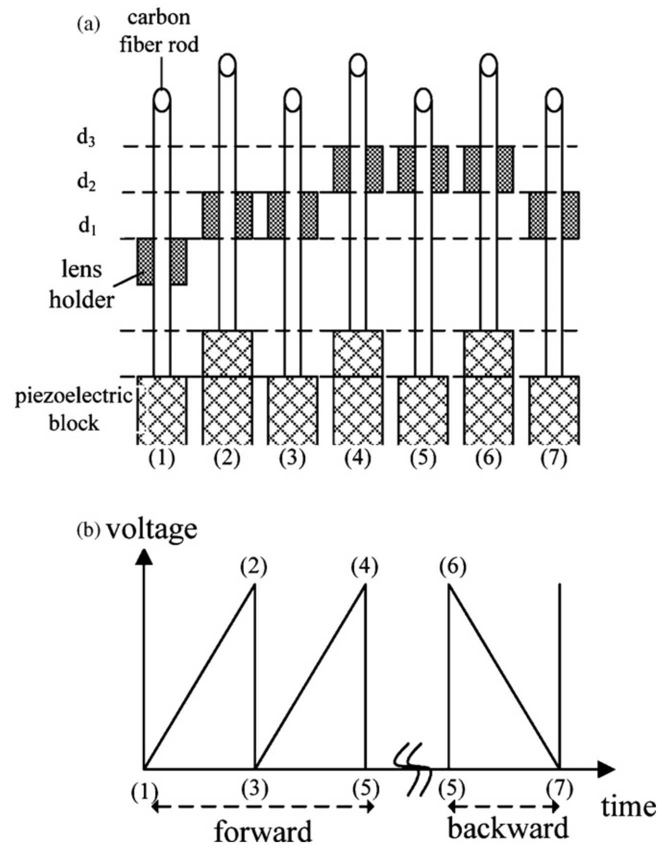

Fig. 2. Operation principle of impact ultrasonic motor and waveform of applied voltage: (a) operation principle and (b) waveform of applied voltage.

Table 1
Piezoelectric properties of fabricated piezoelectric ceramic block

Electromechanical coupling factor, k_{31}	0.32
Mechanical quality factor, Q_m	1500
Piezoelectric constant, d_{33}	340 [pC/N]
Resonant frequency	61 [kHz]

electric block is contracted slowly and, then, the rod and lens holder go back together. With the sequential time processes of pulse waveforms, the lens holder moves backward continually. Accordingly, the lens holder is able to go forward or backward by the control in the saw tooth waveforms of applied voltage. The forward or backward length of lens holder per unit pulse, that is resolution of linear position control, is proportional to the products of maximum voltage, piezoelectric strain constant (d_{33}), and piezoelectric thickness.

3. Experiments

The piezoelectric ceramics for high output devices such as a piezoelectric ultrasonic motor require of materials with high electromechanical coupling factor, high mechanical quality factor, high piezoelectric strain constant, high Curie temperature, and low dissipation factor. The chemical composition of piezoelectric ceramics in this paper is expressed[6]:

$$0.9Pb(Zr_xTi_{1-x})O_3 - 0.1Pb(Mn_{1/3}Nb_{1/3}Sb_{1/3})O_3 (0.49 \leq x \leq 0.55)$$

The raw materials are PbO, TiO_2, MnO, Nb_2O_5, and Sb_2O_3 powders, and the green sheet is prepared by the tape casting method. The piezoelectric block of 13 layers is 2 mm × 2 mm × 1 mm and the internal electrode is Pd–Ag alloy. The multi-layer ceramic block is prepared by the conventional multi-layer piezoelectric ceramic process. Table 1 shows the piezoelectric properties of the fabricated multi-layer piezoelectric ceramic blocks. The resonant frequency of thickness extensional vibration mode in the piezoelectric block is 61 kHz, which is used as operational frequency of applied voltage to the motor. The piezoelectric block in motor fabrication locates at the center of tungsten disk by an adhesive, and the carbon fiber rod adheres on the top side of piezoelectrics simply as shown in Fig. 1. The rod is inserted in lens holder and fixed by plate spring.

4. Results and discussion

Fig. 3 shows the measuring system of ultrasonic motor, and the function generator (HP 33120A, Agilent) and power amplifier (HAS 4012, NF) are used for driving ultrasonic motor. The serial inductor is used for the resonance with the capacitance of piezoelectric ceramics. The saw tooth waveforms for the forward and backward motions of motor operation show in Fig. 2(b). The speed is measured at the end of carbon rod and lens holder by laser vibrometer, as the saw tooth wave pulse is applied to the motor continuously. The dummy weight of 1–5 g instead of lens holder is located for the measurement of speed versus mechanical load characteristics. Fig. 4 shows the speed and current with

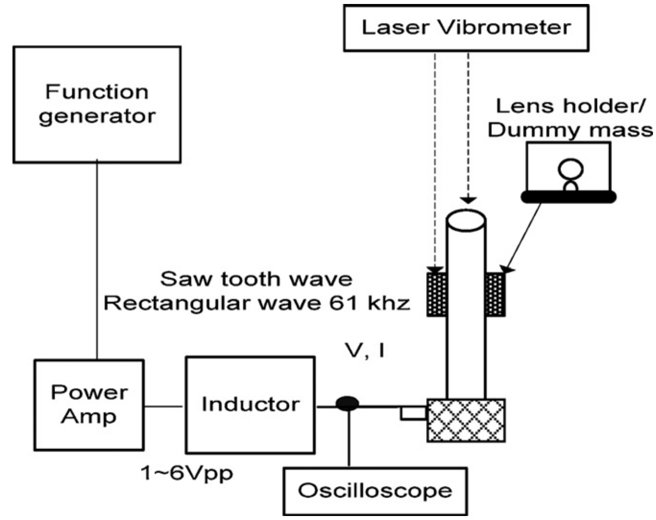

Fig. 3. Experimental set-up.

the applied voltage of saw tooth waveform at 61 kHz for the lens holder of 2 g as a moving object. As the applied voltage increases, the speed and current increase gradually. The speed is 6 mm/s and the maximum dissipation power is 0.1 W at the applied voltage of 10 V_{p-p}.

Fig. 5 expresses the variation of speed and figure of merit with dummy weight of 1–5 g instead of the lens holder, and the applied voltage is 10 V_{p-p} and frequency is 61 kHz. The figure of merit defines for convenience as following equation:

$$\text{Figure of merits} = \frac{s \times m}{V \times I} \left(\frac{\text{mm g}}{\text{V mA s}}\right)$$

where s (mm/s) is the speed of motor, m (g) the dummy weight, V (V) the maximum input voltage, and I (mA) is the input current.

The speed decreases with increasing dummy weight, and this drooping speed versus load characteristics is similar to general speed–load characteristic of ultrasonic motor. However, the figure of merit increases up to dummy weight of 4 g and thereafter it decreases slightly. From these results, it seems that the optimal point in figure of merit of the fabricated motor shows at weight of 4 g. Considering the commercial lens module with the weight

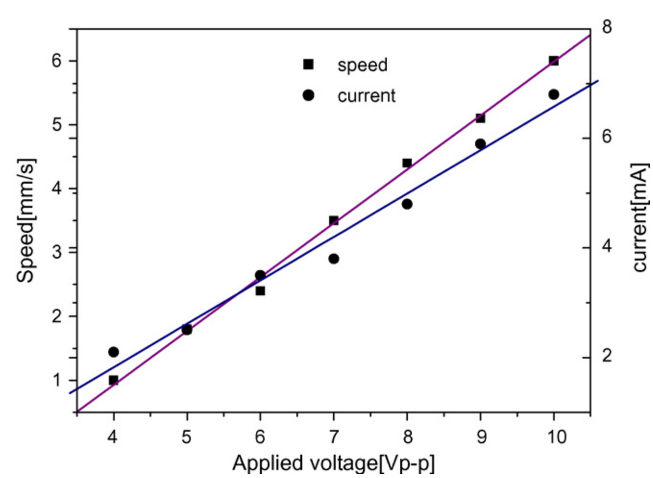

Fig. 4. Speed and current as a function of applied voltage.

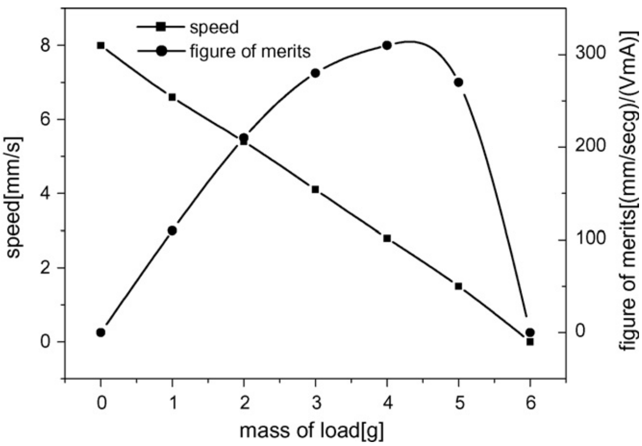

Fig. 5. Speed and figure of merits according to dummy weight.

of around 2 g in general, it is known the appropriate value. The speed is 6 mm/s at object weight of 2 g. It is possible to apply adequately, because the maximum distance of moving lens in the commercial camera phone is 0.5 mm for the control of AF and the maximum required time is about 0.1 s. The ultrasonic motor fabricated in this paper shows the good performance for automatic focus of camera phone. The motor has also simple structure and small size. It is possible to apply to camera of commercial cellular phone presently.

5. Conclusions

Ultrasonic motor is fabricated for AF and optical zoom operation in camera module of cellular phone, and then the performances of the motor is investigated. The proposed impact ultrasonic motor is consisted of tungsten plate, piezoelectric block with 13 layers, and carbon fiber rod and has simple structure relatively. The fabrication process of ultrasonic motor is also simple. Therefore, its fabrication cost is reduced remarkably. From the estimation of speed versus mechanical load characteristic shows the trend that speed decreases with an increase of moving weight. Speed is 6 mm/s and dissipation power is 0.1 W at the applied voltage of 10 V_{p-p} with 61 kHz saw tooth wave, as the weight of camera module is 2 g. It is possible to control ease the forward or backward movement with the change of saw waveform. The ultrasonic motor prepared in this paper is possible to apply on automatic focus and optical zoom for commercial camera phone. For optimal design of the motor, further study on friction system among carbon rod, lens holder, and plate spring will be needed.

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