Characteristics of a Miniaturized Ultrasonic Motor for Auto-focusing of a Mobile Phone

Kee-Joe Lim*, Jong- Sub Lee and Seong-Hwa Kang†**

Abstract - In this paper, the design and characteristics of a novel ultrasonic motor are investigated. Such a motor is appropriate for use in the optical zoom or auto focusing functions of the lens system in mobile phones. Its design and simulation of performances are carried out by FEM commercial software (ATILA). The shape of the motor is similar to a square without one side, on which an optical lens can be mounted. Two sheets of piezoelectric ceramics are adhered to both sides of two legs of the elastic body, respectively. To drive the ultrasonic motor, the voltage is applied to two sheets of piezoelectric ceramics bonded to one leg. The rotation direction can be easily changed by switching the piezoelectric sheets bonded to the other leg, to which voltage is applied. A proto type of the motor is fabricated and its outer size is 10*10*2[mm3] including the camera lens of which the diameter is 7.5[mm]. Its power consumption is about 0.3[W] and the speed of rotation is adjustable from 10 to 200[rpm] according to the applied voltage

Keywords: Auto focusing, Bending Vibration, FEM, Piezoelectric, Ultrasonic Motor

1. Introduction

Recently, the function of digital cameras mounted in PDAs and mobile phones is necessarily equipped by the convergence of information telecommunication technology and multimedia technology. The number of pixels in a camera phone is dramatically increased, which is nearly at equal level with the conventional digital camera. However, the functions of auto focusing (AF) and/or optical zooming in camera phones remain insufficient when compared with the conventional digital camera. AF and/or optical zooming as functions of the camera are necessary because the quality of the photograph is dependent on them. A miniaturized actuator is needed to operate the AF and/or optical zooming function, which is restricted in size due it's being mounted in the in mobile phone and PDA [1]. Currently, the actuators used for AF are mostly stepping motors or DC motors, but their problem is in relation to their size. The minimum size of a stepping motor is 4 [mm] in diameter and its torque is so small that it can't move the lens. Also, the conventional electro-magnetic motor must employ the use of reduction gear to decrease its fast speed and it is difficult to control it's position precisely due to backlash [2]. The ultrasonic motor is a good candidate for this type of purpose. Compared to the conventional electro-magnetic motors, the ultrasonic motor has various advantages. It may be made in a 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; windings, magnets, or brushes are redundant. Highly accurate speed and position control are relatively easy to obtain with the motor using standard feedback control systems, unlike electro-magnetic motors that require complex sensors and controllers to ensure accuracy, particularly with position control. It is capable of delivering high torque at low speed despite its relatively small size, which is excellent for low-speed applications. Unaffected by magnetic fields, it provides a unique capability to deliver motion in electro-magnetic environments. With little rotor inertia and large torque, it is exceptionally responsive with a reaction time as little as a few milliseconds. Finally, it possesses an inherent braking action when power is removed, making it useful for robot and step motor applications [3, 4]. Accordingly, the ultrasonic motor is newly designed for the AF function of camera phones and its vibration mode is analyzed by FEM (Finite Element Method) in this paper. The characteristic of resonance frequency on the thickness of elastic body is also investigated. Based on simulation results, the ultrasonic motor is fabricated and its characteristics are measured.

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2. Design and Simulation of the Ultrasonic Motor

Fig. 1 shows the cross section of the camera module for

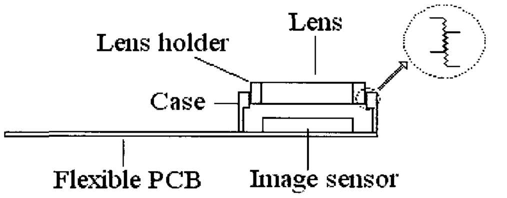


Fig. 1 Schematic of camera module for mobile phone

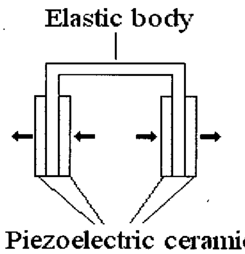
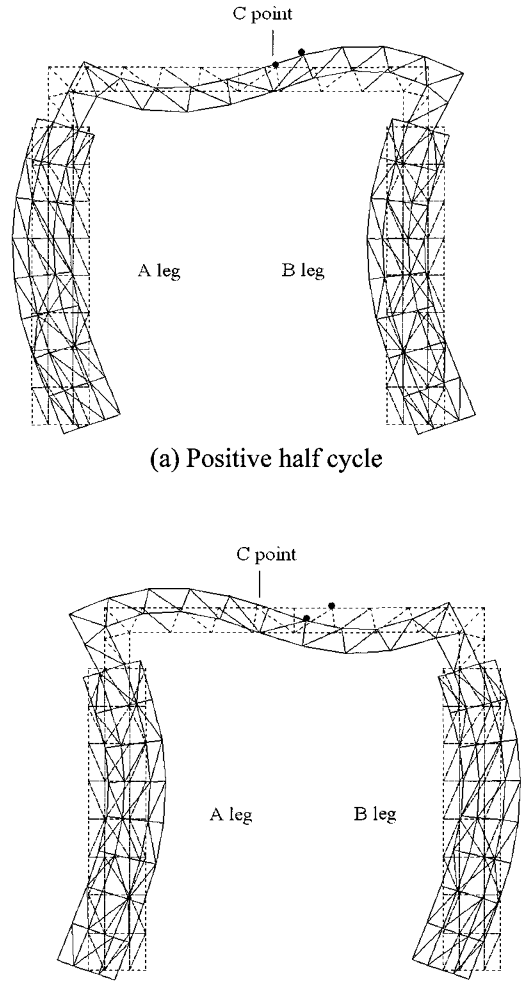


Fig. 2 Structure of newly proposed ultrasonic motor

a mobile phone. The camera module consists of an image sensor, flexible PCB, case, lens, and lens holder that includes a single lens. The lens holder is of annular type with a screw-in edge and its diameter and pitch of screw are mainly 7.5[mm] and 0.35[mm], respectively. If the lens holder rotates 360°, it moves 0.35[mm] linearly. Accordingly, in order for application to the conventional camera module, the most desirable structure of the ultrasonic motor for auto focusing is one that can be inserted into the camera module with a rotary type motor.

Based on the above design concept, the newly proposed ultrasonic motor is shown in Fig. 2. The motor consists of stator and rotor, which is the lens holder. The stator is composed of rectangular type piezoelectric ceramics and has an elastic body in the shape of a square that is missing one side. Piezoelectric ceramic plates are adhered to both sides of the leg of the elastic body in parallel, as indicated in Fig. 2.

Fig. 3 shows the motion principle of the proposed ultrasonic motor. Commercial finite element analysis software (ATILA Ver. 5.2.1) is used to analyze its vibration mode. When voltage is applied to piezoelectric ceramics in A-leg, the elastic body is bended and the standing wave is generated at the whole elastic body because it is finite. Point "C" on the elastic body moves to + X direction during the positive half cycle of applied voltage and – X direction during the negative half cycle due to the bending vibration of A-leg, and also vibrates from + Y direction to – Y direction due to standing wave generated at point "C', as presented in Fig. 3. As vibration to the X and Y directions is mixed, point "C" moves in elliptical trajectory counterclockwise without two phase driving, which is common in conventional ultrasonic motor driving [3, 4]. When voltage is applied to B-leg, it moves in elliptical trajectory clockwise, with the rotor rotating in the reverse direction of elliptical trajectory if the rotor is contacted on point "C". The ultrasonic motor proposed in this paper can be driven by single phase. The motor consists of a simple structure and is very small because there are no added things without a stator.



(a) Positive half cycle

(b) Negative half cycle

Fig. 3 Motion principle of the proposed USM

3. Design and Simulation of the Ultrasonic Motor

Piezoelectric ceramic is fabricated by $0.9(Pb(Zr_{0.51}Ti_{0.49})O_3)–0.1(Pb(Mn_{1/3}Nb_{1/3}Sb_{1/3})O_3$ composition for the newly proposed ultrasonic motor [5, 6]. The fabricated piezoelectric ceramic is stacked to 7-layers and its physical dimension is 6*2*0.35[mm^3] (length*width*thickness). Its piezoelectric and dielectric properties are listed in Table 1.

The elastic body is made from SUS 304, stainless steel, and its shape is formed by mechanical press. Its outer dimension is 10*10*2[mm^3] (length*width*height) and its

Table 1 Piezoelectric and dielectric properties of fabricated piezoelectric ceramic

Electro-mechanical coupling factor, k_{31}	0.32
Mechanical quality factor, Qm	1500
Piezoelectric constant, d33	340[pC/N]
Resonance frequency, fr	275[kHz]
Free capacitance	10[nF]

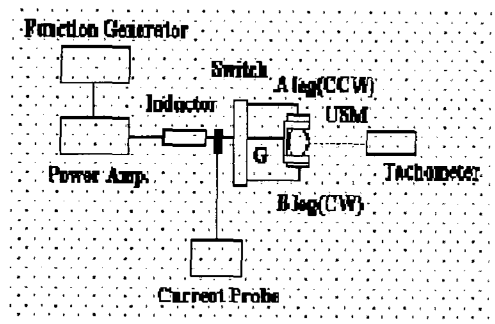


Fig. 4 Driving system of ultrasonic motor

thickness is varied to 0.3[mm], 0.5[mm] and 0.8[mm], respectively. The piezoelectric ceramics are adhered in parallel to the elastic body by epoxy, as seen in Fig. 4. Resonance frequency is measured by impedance analyzer (HP 4194A, Agilent), compared with simulation results by FEM.

The driving system of the ultrasonic motor is shown in Fig. 4. A function generator (HP 33120A, Agilent) and power amplifier (HAS 4012, NF) are used to drive the ultrasonic motor. A series inductor is also utilized to make resonance with the capacitance of the piezoelectric ceramic. The rotation direction of the ultrasonic motor is changed by switch and the speed of rotation is measured by tachometer (M 3632, Yokogawa). Power consumption of the ultrasonic motor is calculated by the product of applied voltage and the current that is measured by the current probe (P6022, Tektronix).

4. Results and Discussion

The change of resonance frequency as a function of the thickness of elastic body is indicated in Fig. 5. The dimension of piezoelectric ceramics is constant. As shown in this figure, as the thickness of the elastic body is increased, the resonance frequency is also increased linearly. This reason can be explained as follows; if we consider the elastic body as a cantilevered beam, its fundamental natural frequency ν is given by eq. (1)

$$\nu = 0.163\frac{h}{l^2}\sqrt{\frac{E}{\rho}} \tag{1}$$

Where, E is the Young's modulus, ρ the density, l the length, and h the thickness [5]. Accordingly, resonance frequency has direct proportion with the thickness of the elastic body.

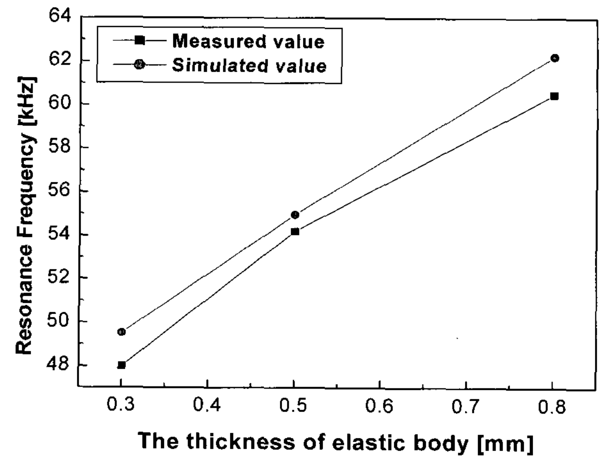


Fig. 5 Change of resonance frequency as a function of the thickness of the elastic body

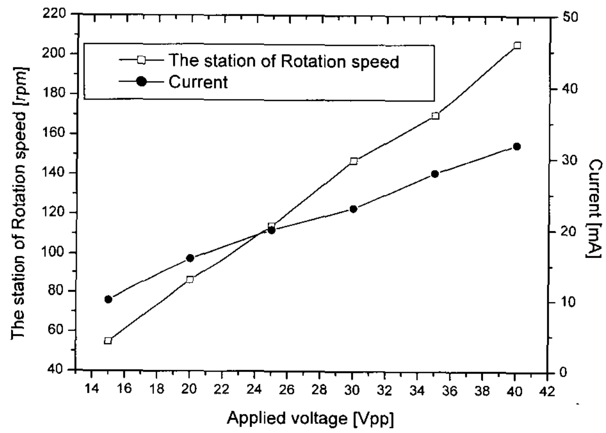


Fig. 6 Speed of rotation and current as a function of applied voltage

Fig. 6 indicates the speed of rotation and current as a function of applied voltage. Where, the thickness of the elastic body is only 0.8[mm] because the 0.3[mm]-thick ultrasonic motor does not rotate, and the 0.5[mm]-thick ultrasonic motor rotates more than 30[Vpp] of applied voltage, but is unstable. It can be considered that the ultrasonic motor employs the use of flexural waves to make the elliptical motion at a point on the beam surface. As the thickness of the beam becomes thinner, the flexural wave may be hard to generate [7]. As shown in Fig. 6, as applied voltage is increased, the speed of rotation and current are also increased, and the speed of rotation and power consumption are maximum 206[rpm] and about 0.3[W] under 40[Vpp] of applied voltage at 60.5[kHz] of resonance frequency, respectively.

Accordingly, it is certain that the newly proposed ultrasonic motor has the compact size and low power consumption necessary to allow it to be appropriate for use in auto focusing systems for mobile phones, compared with the conventional stepping motor.

5. Conclusion

The ultrasonic motor for auto focusing systems for mobile phones is newly designed using FEM commercial software and the performances of the proto type motor are discussed in this paper. Resonance frequency and rotation characteristic depending on the thickness of the elastic body are also investigated. The designed motor consists of stator and rotor, which act as the lens holder. The stator is composed of rectangular type piezoelectric ceramics and the elastic body is in the shape of a square that is missing one side. Piezoelectric ceramic plates are adhered to both sides of the leg of the elastic body in parallel. According to the FEM analysis results, bending vibration is generated on the one leg with attached piezoelectric ceramic plates when voltage is applied to the plate, and a point on one side without piezoelectric ceramic is displaced in a longitudinal direction. The standing wave is generated because the elastic body consists of finite cantilever, and displacement to transverse direction is also generated. Accordingly, the flexural wave is generated in the arm without piezoelectric ceramic plate. The movable body contacted with surface of the arm can rotate. The motor can be driven by single phase, not two phase driving. The motor also has some advantages, which are simplicity of structure and thinness compared with the conventional stepping motor. As the thickness of the elastic body is increased, the resonance frequency of the ultrasonic motor is decreased like in the case of the cantilever beam in which the resonance frequency is in direct proportion to the thickness. Based on the results of FEM analysis, the square type ultrasonic motor is fabricated where the thickness of the elastic body is 0.8[mm] because the flexural wave is difficult to generate as its thickness diminishes. So, the rotation is unstable in 0.3[mm] and 0.5[mm] thickness. And its size is 10*10*2[mm^3] including the lens holder. As an experimental result, as applied voltage is increased, the speed of rotation and current is also increased. When applied voltage is 40[Vpp], the speed of rotation and power consumption are maximum 206[rpm] and about 0.3[W], respectively. The output torque is sufficient for operating the auto-focusing lens. The newly proposed ultrasonic motor, which is thin and miniaturized shows low power consumption, compared with the conventional stepping motor, and is available to application for the auto focusing actuator systems of mobile phones and PDAs.

References

[1] Yoshiaka Hata et al., "Linear Actuator", US Patent, Pub. No. US 2003/0222538, pp. 1 – 12, 2003.

[2] Burhanettin KOC, et al., "An Ultrasonic Motor Using a Metal-Ceramic Composite Actuator Generating Torsional Displacement", Jpn. J. Appl. Phys., Vol. 37, No. 10, 5659-5662, 1998.

[3] Kentaro Nakamura, et al., "Ultrasonic Stepping Motor Using Spatially Shifted Standing Vibrations", IEEE Trans. On UFFC, Vol. 44, No. 4, pp. 823 – 827, 1997.

[4] Faa-Jeng Lin, "Fuzzy Adaptive Model-Following Position Control for Ultrasonic Motor", IEEE Trans. On PE, Vol. 12, No. 2, pp. 261 – 268, 1997.

[5] Kee-Joe Lim, Jong-Sub Lee, The transactions of KIEE, 49 (3), 155 (2000).

[6] Kee-Joe Lim, Jong-Sub Lee, Trans. on electrical and electronic materials, 5 (2), 76 (2004).

[7] Toshiiku Sashida, et al., "An Introduction to Ultrasonic Motor", CLARENDON PRESS, pp. 92-93, 1993.

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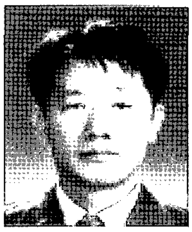

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