p형태의 초음파모터의 특성평가

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Characteristics of p-shaped Ultrasonic Motor

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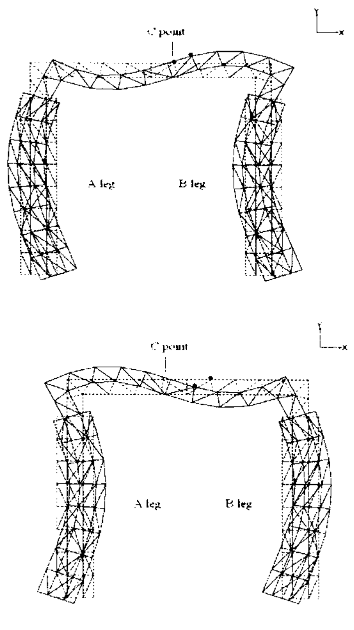
Abstract- *In this paper, the design and characteristics of a* π-shaped ultrasonic motor which is applicable to optical zoom operation of lenssystem for mobile phone are investigated. Its design and simulation of performances are carried out by FEM (finite element method) commercial software. As a simulation result, by applying voltage with single phase, a combined vibration is produced at the surface of an arm of stator. The prototype of motor is fabricated and its outer size is 8*4*2 mm^3 including the cylindrical steel rod of 2 mm in diameter as rotor. The motor exhibits a maximum speed of 500 rpm and a power consumption of 0.3 W when driven at 20 Vpp and 64 kHz.

1. Introduction

Recently, the function of a digital camera mounted in a PDA and a mobile phone is necessarily equipped by the convergence of information telecommunicationtechnology and multimedia technology. The number of pixel in camera phone is dramatically increased, which is nearly at equal level with the conventional digital camera. However, the function of automatic focusing(AF) and/or optical zooming in camera phone are not yet sufficient, comparing with the digital camera. AF and/or optical zooming in camera function is necessary because the quality of photograph depends on them. A miniaturized actuator is needed to operate AF and/or optical zooming function, which is limited in size for mounting in mobile phone.[1] The actuator which used for optical zoom is mostly stepping motor or DC motor, but their problem is in the sizeand the performances. The minimum size of a stepping motor is 4 mm in diameter and its torque is not sufficient to move the lens. Also, the conventional electro-magnetic motor has to use the reduction gear to decrease its fast speed and is hard to control precisely due to its backlash.[2] The ultrasonic motor(USM) can overcome these problems in electro-magnetic motor. Compared to typical electromagnetic motors, USM has various advantages.[3,4] It may be manufactured 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 notnecessary. Highly accurate speed and position control are relatively easy to obtain with the motor using standard feedback control systems, unlike electro-magnetic motors which require complex sensors and controllers to ensure accuracy, particularly with position control. It is capable of delivering high torque for its size at low speed, which is excellentfor 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 response 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.[5,6] The USM is newly designed for optical zoom function of camera phone and its vibration mode is analyzed by FEM(Finite Element Method) in this paper. And based on simulation results, a prototype USM is fabricated and measured its characteristics.

2. Operation Principle of Motor & Simulation of Vibration

In general, ultrasonic motor is driven by mechanical vibration such as the traveling wave and a combination of two vibration modes. The structure of the ultrasonic motor by the traveling wave is very complex. Its driving circuit is also complex and expensive because of the driving method of input voltage with two phases. Accordingly, in this paper, we focus on to design motor driven by a single phase input voltage with simple structure. The stator structure of the newly proposed ultrasonic motor is shown in Fig. 5. The stator is composed of rectangular-shapedpiezoelectric ceramic plates and the π-shaped elastic body. The piezoelectric plates are bonded onto both sides of the elastic legs in parallel. The motion principle of the proposed ultrasonic motor is shown in Fig. 1. The commercial finite elements analysis software (Atila, Magsoft Co.) is used to analyze its vibration mode. In principle, it is important how to generate an elliptical motion of a given point mass on the surface of stator, which is contacted with the surface of rotor in ultrasonic motor.[2-4] A motion of the point "C" on the center arm of π-shaped stator as a point mass during a period of input voltage is investigated as following. If 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. The point "C" on the elastic body moves to +X direction during positive half cycle of applied voltage and -X direction during negative half cycle due to bending vibration of A leg. That is, the bending vibration by piezoelectric ceramic is converted to the displacement of X direction because of the π-shaped elastic body. Simultaneously, the point "C" on the elastic body also is displaced from +Y direction to -Y direction, as shown in Fig. 1. As the vibration to X and Y direction is combined, the point "C" moves in elliptical trajectory counterclockwise direction by means of application of only a single phase voltage, not two phase voltage driving which is common in conventional ultrasonic motor[2,3,4]. If the rotatable cylindrical rod as a rotor is contacted with the point "C" and impressed by spring as shown in Fig. 5, the rod can be rotated to clockwise direction. If the voltage is applied to B-leg, the point "C" moves in elliptical trajectory clockwise, and the rod will be rotated to counterclockwise direction. The rotation direction of the rotor(rod) can be easily changed by changing the leg which is applied voltage. We have worked on π-shaped ultrasonic motor previously as shown in Fig. 1.[7] In the figure, piezoelectric ceramic is bonded to an elastic body with bimorph type, however its fabrication process is complex and the cost becomes expensive. In order to reduce the cost, bimorph type is changed to unimorph type. The unimorph type means that piezoelectric ceramic plate is bonded onto one face of a leg in the π-shaped stator, but the other hand the piezoelectric plates are bonded onto both faces of a leg in bimorph type. A simulation result on displacement in unimorph type stator is shown in Fig. 2. The displacement of the unimorph type ultrasonic motor is relatively small but its vibration pattern is almost similar to the bimorph type so that it can be also realized an ultrasonic motor.



(a) Positive half cycle
(b) Negative half cycle
Fig. 1 The motion principle of the proposed ultrasonic motor

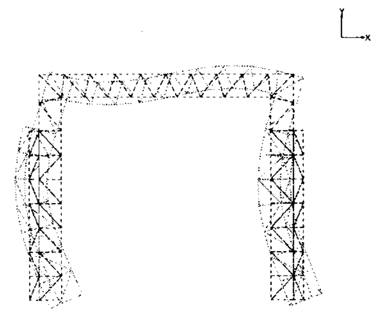


Fig. 2 The displacement pattern of unimorph type ultrasonic motor

In Fig. 1 and Fig. 2, the thickness of the elastic body is 0.6 and 0.8 mm, respectively. As the size of the mobile phone becomes small and slim, the size of actuator must be minimized. So, as the thickness of the elastic body is changed from 0.3 to 0.8 mm, the displacement pattern is simulated. The result on the elastic body of 0.3 mm inthickness is shown in Fig. 3. Its pattern is different from Fig. 1 and Fig. 2 and there is no displacement to X direction. The reason can be explained as following. As the thickness of the elastic body becomes thinner, the displacement generated by piezoelectric ceramic can't transfer to the edge of the elastic body and there is no displacement to X direction. Accordingly, the thickness of the elastic body must be more than 0.3 mm to make the ultrasonic motor.

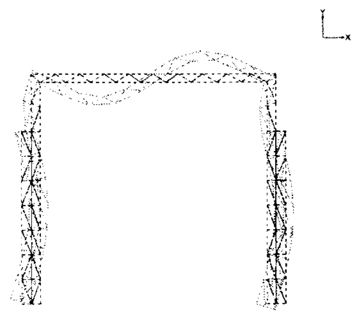


Fig. 3 The displacement pattern of the elastic body of 0.3 mm in thickness

Fig. 4 shows the simulation result in the case that the length of the center arm is reduced to 4 mm. As shown in Fig. 4, its pattern is similar to Fig. 1 and Fig. 2 and it can be realized ultrasonic motor.

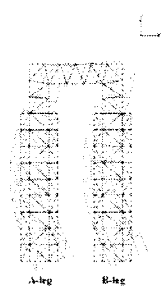


Fig. 4 The displacement pattern of the elastic body with center arm of 4 mm in length

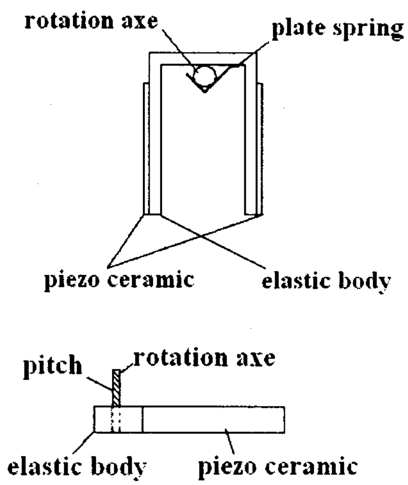
3. Fabrication of Ultrasonic Motor

Piezoelectric ceramic for the newly proposed motor is fabricated with a composition; $0.9(Pb(Zr_{0.51}Ti_{0.49})O_3)$ - $0.1(Pb(Mn_{1/3}Nb_{1/3}Sb_{1/3})O_3$. The fabricated piezoelectric ceramicplate is stacked to seven 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.

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

Table 1 Piezoelectric and dielectric properties of fabricated piezoelectric ceramic

The elastic body makes from SUS 304, stainless steel, its dimension is 8*4*2 mm^3 (length*width*height) and its thickness is varied from 0.3 to 0.8 mm, respectively. The piezoelectric ceramic plate is bonded onto outer face of each leg of the elastic body in parallel by epoxy, as shown in Fig. 5. A rotatable cylindrical stainless steel rod of 2 mm in diameter as a rotor is contacted with the inner surfaceof the center arm of π-shaped elastic body and impressed with plate spring. The rotor is divided to two parts in length, which a part contacting with stator is coated with lining materials and the other part is machined a screw with 0.35 mm in pitch for operating optical zooming function. Resonance frequency of stator is measured by impedance analyzer(HP 4194A, Agilent), compared with simulation results by FEM.



(a) Top view
(b) Cross section
Fig. 5 The structure of the proposed ultrasonic motor

The driving system of ultrasonic motor is shown in Fig. 6. A function generator(HP 33120A, Agilent) and a power amplifier(HAS4012, NF) are used to drive the test ultrasonic motor. A series inductor is also used to make resonance with capacitance of piezoelectric ceramic. The rotation direction of ultrasonic motor is changed by mechanical switch. Therotation speed is measured by tachometer(M 3632, Yokogawa). Power consumption of ultrasonic motor is calculated by the product of the voltage and the current which is measured by current probe(P6022, Tektronix) and oscilloscope.

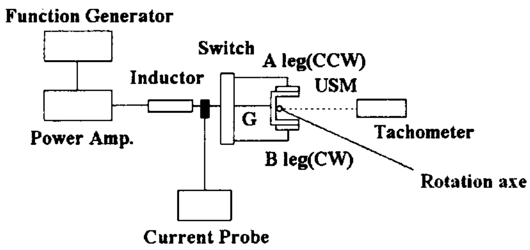


Fig. 6 The driving system of ultrasonic motor

4. Results and Discussion

The change of resonance frequency as a function of the thickness of elastic body is shown in Fig. 7. The dimension of piezoelectric ceramics is fixed. As shown in Fig. 7, as the thickness of elastic body increases, resonance frequency also increases linearly.

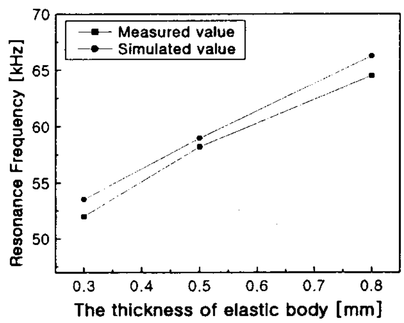


Fig. 7 The change of resonance frequency as a function of the thickness of elastic body

This reason can be explained as following.If we consider the elastic body as a cantilevered beam, its fundamental natural frequency is given by

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

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

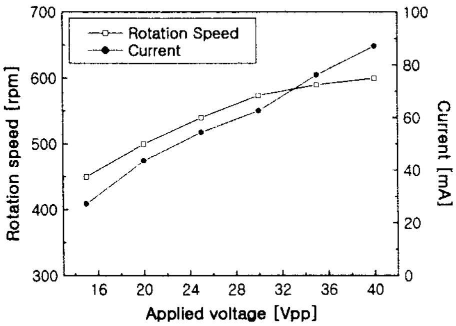


Fig. 8 Rotation speed and current as a function of applied voltage

Fig. 8 shows the rotation speed and current as a function of applied voltage. Where the thickness of elastic body is only 0.8 mm because 0.3 mm-thick ultrasonic motor does not rotate, and 0.5mm-thick motor rotate more than 30 Vpp of applied voltage, but unstable. As the thickness of elasticbody becomes thinner, the flexural wave may be hard to induce. Also, when applied voltage is more than 30 Vpp, rotation speed is saturated because mechanical dissipation increased due to the heat generation in piezoelectric ceramic. The prototype of motor is fabricated and its outer size is 8*4*2 mm^3 including the cylindrical steel rod of 2 mm in diameter as rotor. The motor exhibits a maximum speed of 500 rpm and a power consumption of 0.3 W when driven at 20 Vpp and 64 kHz.

5. Conclusion

A π-shaped ultrasonic motor for an optical zooming system for mobile phone is newly designed using FEM commercial software and the performances of the test motor are discussed in this paper. As the FEM analysis results, a combination of two vibration modes is induced at the center arm of π-shaped elastic body, when driven at only a single phase voltage. It is also shown that an elliptical motion of a given point mass on the surface of the arm is generated, which is contacted with the surface of rotor in ultrasonic motor. Based on the simulation results, the prototype of motor is fabricated and its outer size is 8*4*2 mm^3 including the cylindrical steel rod of 2 mm in diameter as rotor. The piezoelectric ceramic plate stacked seven layer is bonded onto a face of each leg with unimorph type. To drive the ultrasonic motor, the voltage is applied to one piezoelectric ceramic plate. To change the rotation direction, applied voltage can be just changed to the other piezoelectric ceramic plate. The motor exhibits a maximum speed of 500 rpm and a power consumption of 0.3 W when driven at 20 Vpp and 64 kHz. It is concluded that π-shaped ultrasonic motor proposed in this study has a very simple structure and small in size. Furthermore, the performances of the motor including power consumption, rotation speed, output torque, and efficiency are sufficient for application of optical zooming and automatic focusing actuator. However driving voltage is needed to reduce.

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