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Motional characteristics of thin piezoelectric rotary motor using cross shaped stator

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Abstract New type of cross shaped ultrasonic rotary motor was designed and fabricated using a thin brass plate. Cross shaped stator was comprised by attaching ceramic plates on both sides of thin brass plate. When two harmonic voltages which have 90^{o} phase difference were applied to ceramics, the symmetric and anti-symmetric displacements were generated at inside tips to make the elliptical motion. The finite element analysis (ATILA) was used for simulating the motional pattern of contact tips of the stator. Elliptical motions of the contact tips of the stator were consistently obtained at off resonance frequencies. From a prototype motor, speed of 500 rpm was obtained at 16 (V_{rms}).

Keywords Thin ultrasonic rotary motor · Cross shaped stator · Four contact tips · Elliptical motion · FEM

1 Introduction

Recently, demands for small motors were rapidly increased especially in area of electronic appliances [1, 2]. Since electromagnetic motors have a limitation of miniaturization, ultrasonic motors can be an alternative of it for a small space. Ultrasonic motors can produce high torque at low speed with high efficiency, and it can be applied as a gearless simple motor for small electronic devices like camera zoom lens or cell phone. Also, ultrasonic motors produce no electromagnetic interference [3–5]. In previous paper, new type of ultrasonic rotary motor which has cross shaped stator was proposed [6]. Because the stator looks like hollow cross, when a rotor is placed at the center of the cross shaped stator, stator and rotor contact through the four inner tips of the stator. The elliptical displacements of the four tips which are produced by bending of ceramics rotate the rotor using frictions between the tips and outer surface of the rotor. If we make a big hole on a rotor as a path of a light, and attach a zoom lens on a rotor, this zoom lens can be controlled by the motor.

Using similar structure, another new type of motor which can be made easily and cheaply is described in this paper. A thin brass plate was used as a cross shaped vibrator and eight ceramic plates were attached on upper side and bottom side of the brass plate, respectively. From this thin stator, elliptical displacements of the four contact tips were obtained and 500 rpm of speed was measured.

1.1 Structure and principle of motors

Figure 1 shows structure of the cross shaped stator. The stator looks like a cross, as two hollow bars were vertically crossed. This motor was named cross type by the reason of shape of the stator. As in the figure, eight ceramic plates were attached on a thin brass plate. The thickness of the brass plate was 0.2 mm.

By combining the polarization directions of ceramics and the applied electric fields on ceramics as showed in Fig. 2, the brass plate was resonated at various frequencies and the elliptical displacements of the four contact tips were obtained at some frequencies.

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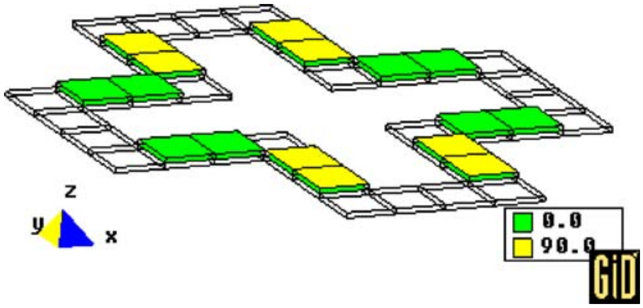

Fig. 1 Structure of the cross type stator

When ceramics were attached on only one side of the plate, useless three dimensional fluctuations were occurred at the four tips, because the brass plate was thin. By attaching ceramics on both sides of the brass plate, stable two dimensional motions were obtained. At each arms of the brass plate, upper side ceramics and bottom side ceramics produce vibrations which are symmetric to the brass surface. Because ceramics on both sides of the brass plate make same vibrations, it is enough to explain a principle of the stator by considering of only one side.

Figure 3(a) shows directions of polarization and electric field on the ceramics. Points A, B, C and D are the contact points between the stator and rotor. As in Fig. 3(b), each contact points have two arms which have polarized ceramics. By applying two electric fields which have 90° phase difference on the ceramics, each contact points make rotational displacements as in Fig. 3(c). These rotational displacements will be transferred to the rotor by frictions between the contact points and surface of the rotor, and the rotor can be rotated to a certain direction.

2 Finite element analysis of stators

A finite element analysis program, ATILA (ver.5.2.4) was used for simulating displacements of the stator. As vibrating material, brass plate of 0.2 (mm) thickness was prepared by cutting. The arms where ceramics will be attached have 4-mm width and 15-mm length. Afterward, this cutting method can be replaced by punching method not only for reducing the product cost but also for clearing the rudeness of cutting edge. Ceramics of 0.5-mm thickness were attached on both sides of the brass plate using conducting adhesive. The brass plate worked as a common electrode of the ceramics. As one of conditions for simulation, three kinds of clamping were given for the stators so called as free, mid surface and end surface clamps.

Figure 4(a) is an admittance curve for the stator, which was clamped at middle areas of the four ending surfaces of the cross. It has three peaks of resonance frequencies. As in Fig. 4(b), at first resonance frequency of 82 kHz, the contact tips were fixed like nodes and another parts of stators moved. At second resonance frequency of 99 kHz the contact tips vibrated on a line of tangential to a rotor surface. At third resonance frequency of 108 kHz the contact tips vibrated on a line of vertical to a rotor surface. These motions of the tips are useless for rotating a rotor. Useful elliptical motions of the tips were obtained at off-resonance frequencies of 75 and 105 kHz, as in Fig. 4(c).

At all of three clamping conditions, there were commonly three resonance peaks and the movement patterns of the tips were almost same. The resonance frequencies of the stator which was clamped at end surfaces were slightly moved to higher frequencies.

3 Experiments and discussions

Cross shaped thin motor was fabricated using same size and materials of simulated stator. Figure 5 shows photos of the fabricated stator. Hollow cross shaped brass plate of 0.2-mm thickness and 4-mm width was made by cutting. The lengths of the arms were 15- and 0.5-mm thick ceramics were attached on both sides of it. The stator was fixed by screws at four ends of the cross. Rotor has inclined

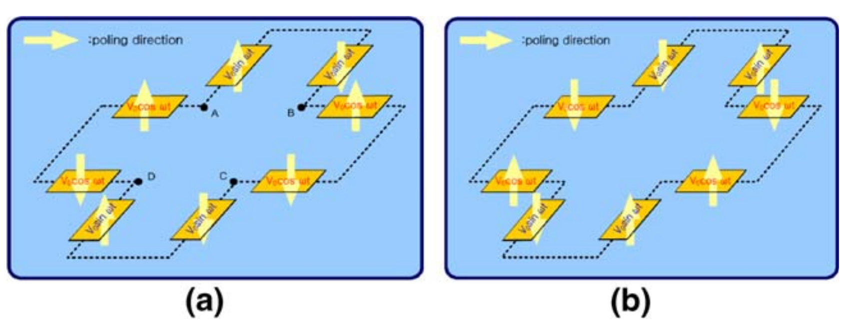

Fig. 2 Polarization and electric fields on ceramics, (**a**) ceramics on upper surface; (**b**) ceramics on bottom surface

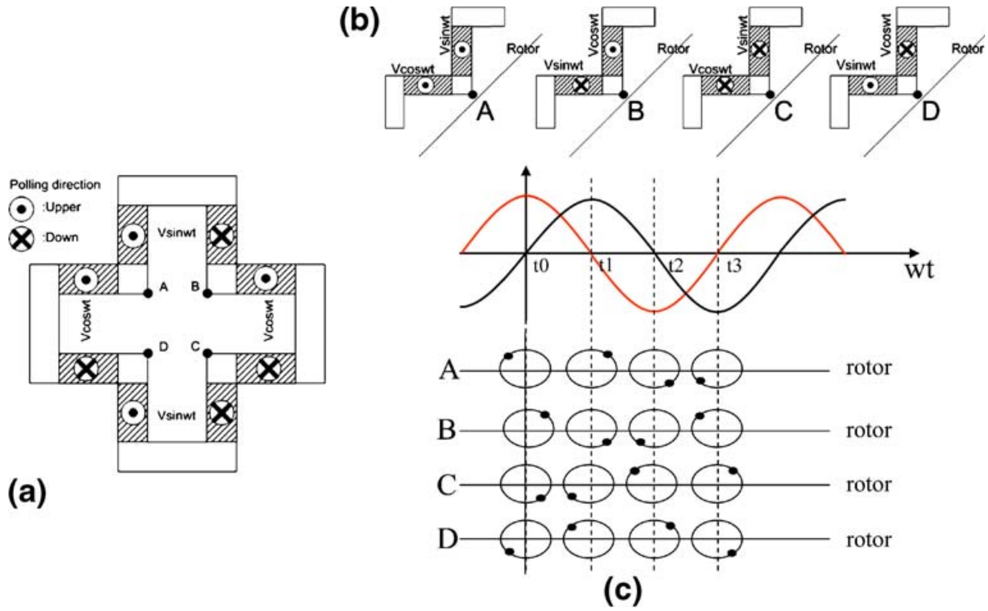

Fig. 3 Generation of elliptical displacements at four contact tips, (**a**) designating the four contact points on the stator; (**b**) polarizations and electric fields on ceramics at each contact points; (**c**) elliptical motions of the contact tips

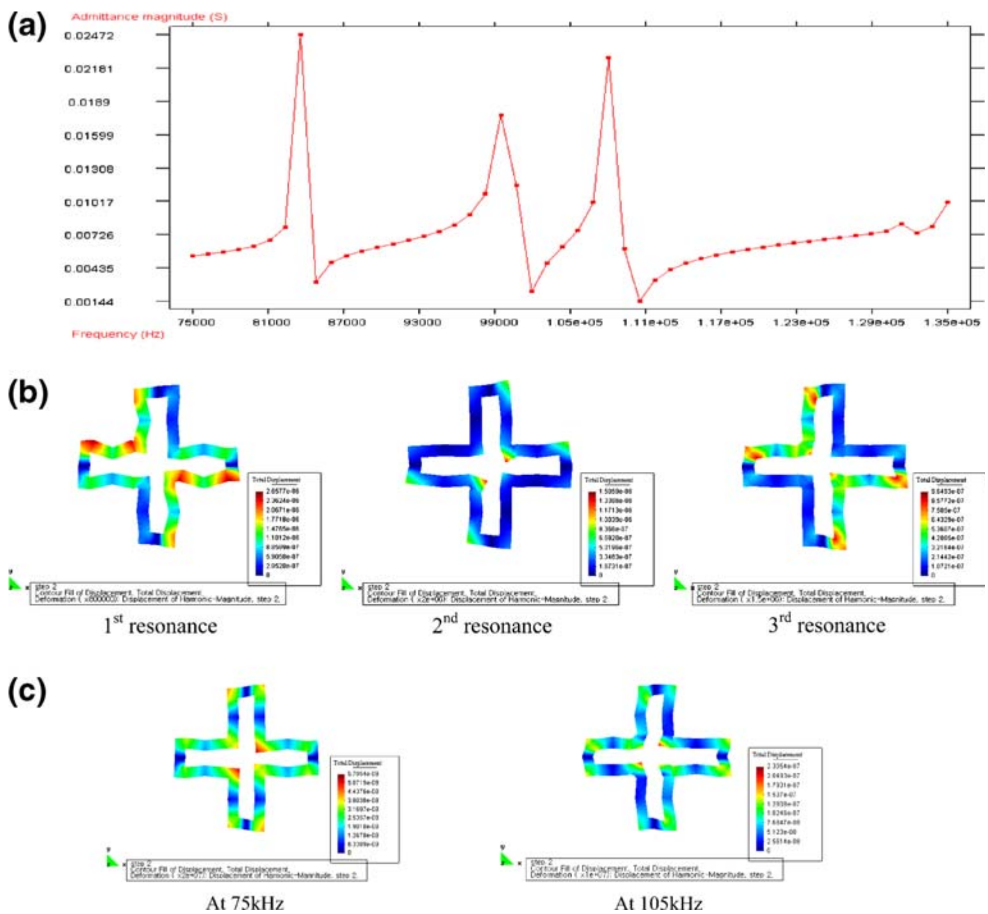

Fig. 4 Simulation results for the stator which was clamped at mid surface, (**a**) admittance curve; (**b**) motional patterns at resonance frequencies; (**c**) elliptical motions of the tips at off-resonance frequencies

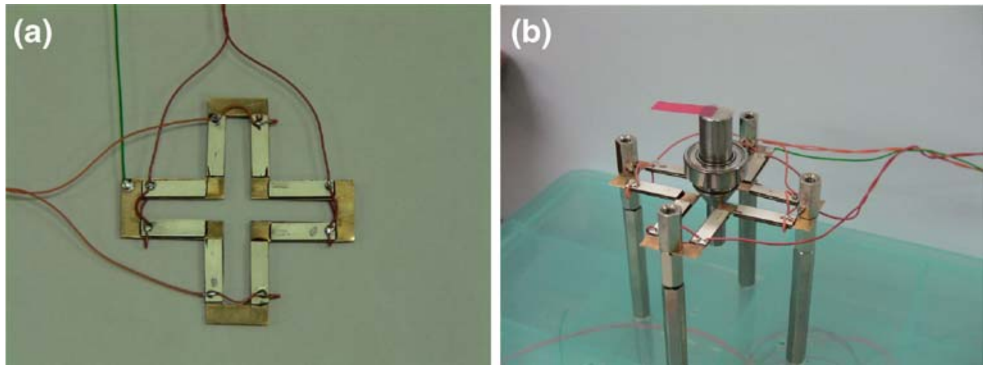

Fig. 5 Photos of the fabricated stator, (**a**) stator and lead wires; (**b**) clamping stage and a rotor on a stator

surface like a corn to contact easily with the four contact tips as in Fig. 5(b).

Speed and torque of the motor were measured by changing the applied voltages. As voltage sources, sinusoidal waves from a frequency generator (agilent, 33120A) were amplified by power amplifiers (NF, HSA4051). Phase shifter circuit was used for making 90^{o} phase difference between the two waves. Figure 6 shows changes of the speed and torque of motors depend on the applied voltages at 92.5 kHz which was the frequency of maximum speeds. Same as in the finite element analysis [Fig. 4(a)], this frequency was at off-resonance area between the first and second resonance frequencies. By applying relatively low voltages, high speeds were obtained as in Fig. 6(a). The maximum speed of 500 rpm was obtained at 16 (V_{rms}). As in Fig. 6(b), relatively low torque was obtained because only the mass of a rotor was a preload of the motor. Under the voltage of 8 (V_{rms}), torque couldn't measured because the frictions between a rotor surface and four contact tips were not sustained by slip. By applying optimal preload using spring and ball bearing, a stable and high torque motor could be anticipated. Changes of rotational directions were done by changing the driving frequency and also by changing the phase of applied voltages.

4 Conclusions

New type of cross shaped ultrasonic rotary motor was designed and fabricated using a thin brass plate, especially for developing a thin motor which must be useful for thin spaces like digital camera or cell phone. As a cheap way to prepare a thin metal plate, punching method will be proposed.

By simulation of a prototype motor using ATILA, motional pattern of the four contact tips depending on frequencies was obtained. The influence of clamping conditions was also simulated. In simulations, the elliptical motions of four contact tips were consistently occurred at off-resonant frequencies and the fact was proved by an experiment of the fabricated motor. Relatively high speed was obtained at low voltage and the speed of motor could be controlled by changing the applied voltages. Rotational direction of motors also could be changed by phase or frequency changes.

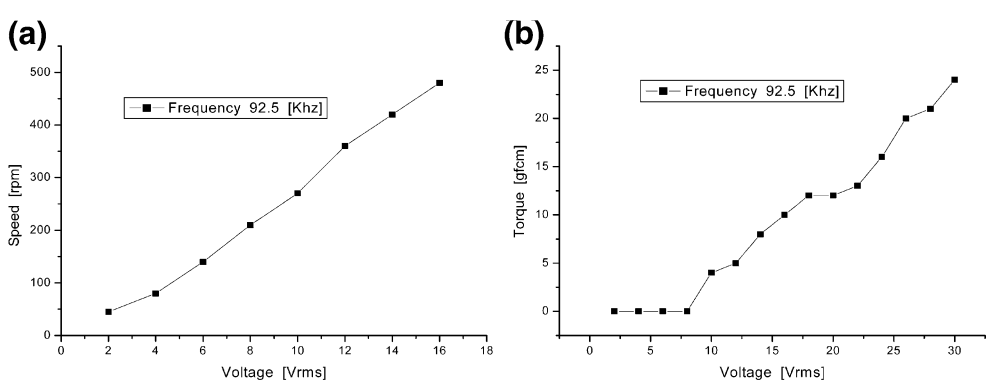

Fig. 6 Driving characteristics of the fabricated motor, (**a**) Speed versus voltage; (**b**) torque versus voltage

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