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Driving Characteristics of a Hexadecagon-shaped Ultrasonic Motor

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A novel hexadecagon-shaped ultrasonic motor is proposed. The stator is easy to fabricate because of its simple structure. The stator of the hexadecagon ultrasonic motor is composed of an elastic ring and ceramics. The elastic ring has sixteen sides and angles. The eight ceramics are attached on the outer surfaces of the eight sides of the ring. When rotor of the cylindrical shaft is inserted inside the ring stator, the central lines of the sixteen sides of the stator hold the shaft with slight pressures. This slight pressure is the preload of the motor and it can be controlled by the radius and the thickness of the ring. When two AC voltages that have a 90-degree phase difference are applied to the eight ceramics, elliptical displacements of the inner surface of the ring are obtained. These elliptical displacements of the inner surface rotate the shaft rotor through friction. The proposed hexadecagon ultrasonic motor was designed and analyzed by using a finite element analysis (ATILA), depending on the number of piezoelectric ceramics and hexadecagon modes. As a result, the stator was optimally designed by defining the output displacement characteristics, which depend on changes in the chosen parameters.

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I. INTRODUCTION

The Recently, a rapid increase in demand has been seen for small motors for electronic appliances with the development of the industrial technology [1]. Because the miniaturization of electromagnetic motor has limits, ultrasonic motors are a viable alternative for small spaces. Also, motors should have an simple manufacturing process to overcome the limits of miniaturization [2–4].

In this paper, an hexadecagon-shaped ultrasonic motor that has sixteen contact points is proposed, and the output characteristics, which were simulated by using the ATILA(FEM, Finite Element Method) program are reported. This motor has a hexadecagon-shaped stator and eight rectangular plate ceramics. This motor can be fabricated with a small and simple structure. The performance of the motor was analyzed for various on stator materials, thicknesses and widths of the piezoelectric ceramic and elastic ring. For tests of the basic movements, a prototype motor was chosen and fabricated, and its speed characteristic was measured experimentally.

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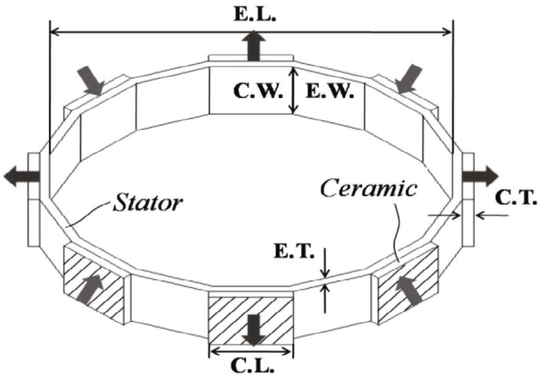
II. STRUCTURE AND PRINCIPLE OF THE MOTOR

Figure 1 shows the structure of the hexadecagon shaped ultrasonic motor. The stator of the motor consists of a hollow hexadecagon-shaped metal ring and eight piezoelectric ceramics attached on outer surface of the elastic body. The sixteen metal bars that make up the ring stator have identical sizes and bilateral symmetry. If a rotor surface is placed on the stator, the rotor and the stator will be in contact through sixteen contact points at the centers of the 16 inner sides of the hexadecagon stator. Abbreviation for the parameters of the stator used for the design of the motor are given in Table 1. The polarization directions of the piezoelectric ceramics are anti-parallel arranged with opposite side ceramics as shown in Fig. 1 and two sinusoidal voltages which have a phase difference of 90 degrees are applied to each ceramic, elliptical displacements are generated at the contact points on the inner surface [5]. These elliptical displacements of the 16 contact points rotate the rotor by using friction forces. The same phase voltages (sine) are applied to the 4 confronting ceramics, and 90-degree lag voltages (cosine) are applied to the remaining 4 ceramics. When voltages at resonance frequencies are



C.T.	Ceramic Thickness
C.W.	Ceramic Width
C.L.	Ceramic Length
E.T.	Elastic body Thickness
E.W.	Elastic body Width
E.L.	Elastic body Length

Fig. 1. Structure of the stator proposed for an ultrasonic motor and abbreviation table.

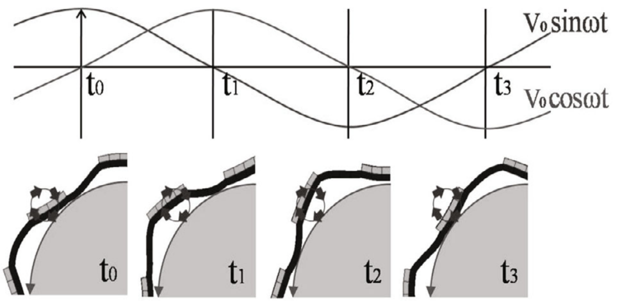


Fig. 2. Principle of the elliptical motion.

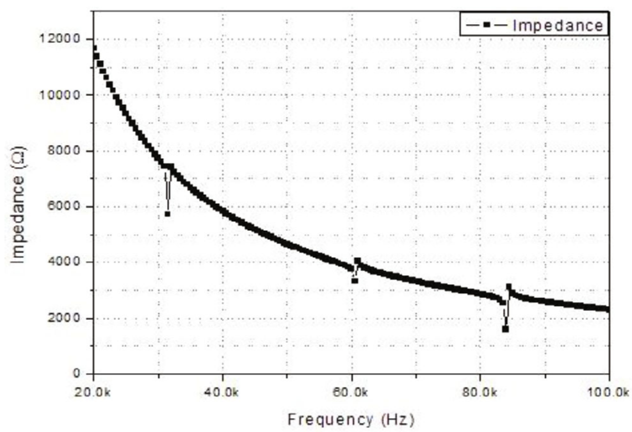


Fig. 3. Impedance curve of motor ET0.5 CT1 CW4.

applied in this way, a combination of longitudinal and bending waves occurs and elliptical motions of the contact points are produced, as shown in Fig. 2. Figure 2 shows the principle of elliptical motion at one contact point among the 16 points. Through one cycle of the applied voltages (from t0 to t3), one elliptical motion of the points is completed, and the same elliptical motions are generated sequentially at the 16 points to rotate a rotor [6,7]. When a surface was assumed to be a cantilever, the two piezoelectric ceramics are attached to three surfaces. Two piezoelectric ceramics have a bending mode and a longitudinal mode at the same time, which is reminiscent of waves, with the synthesis of two vibration modes. The rotor rotates based on such a principle.

III. FEM SIMULATION AND RESULTS

ATILA, a program, was used to analyze the driving characteristics for various sizes of the stator. The piezoelectric ceramics used for the simulations were NEPEC6 from Tokin Ltd. In this paper, the names of stators are given by using the sizes of the parameters. For example, if the length of the elastic ring, the thickness of the elastic ring, the thickness of the ceramic and the width of the ceramic are 20 mm, 1 mm, 0.5 mm, and 2 mm, respectively, the stator the named as EL20ET0.5CT1CW4.

Figure 3 shows the impedance characteristics obtained by using the FEM. From this curve, resonance and anti-resonance frequencies can be found. Based on this, the model for the maximum displacement was selected. Selected motors were analyzed by changing the ET (elastic thickness), CT (ceramic thickness) and CW (ceramic width). As the driving frequency for analyzing the motor, a frequency of 84 kHz was selected from mode 3 of the impedance curve.

Figure 4(a) shows displacements of one contact point of the stator ET0.5 CT1, where three kinds of ceramic widths (CWs) were used: 2, 3, and 4 mm. Fig. 4(b) shows displacements of one contact point of the stator ET1CT1, where three kinds of CWs were used: 2, 3, and 4 mm. Similarly, Fig. 4(c) shows the displacements of one contact point for the stator ET1CT0.5, where three kinds of CWs were used: 2, 3, and 4 mm. By comparing magnitudes of the displacements for the three stators, which have different ratios for the thickness of the elastic body to that of the ceramic, an optimal ratio was confirmed to by ET : CT = 0.5 : 1, which showed the biggest displacements as shown in Fig. 4(a). This result means that a stator with thinner elastic rings is easier to vibrate by ceramics. Also, as shown in Fig. 4(a), larger displacements were obtained for larger CWs.

Figures 4(b) and (c) show that a thicker ceramic is favorable for vibrating an elastic ring of the same thickness. The effects of the ceramic width and vibrating patterns in Fig. 4(b) and (c), where the thickness of the elastic ring is seemingly burdened for the ceramics, will be analyzed in future works. In this simulation, the applied

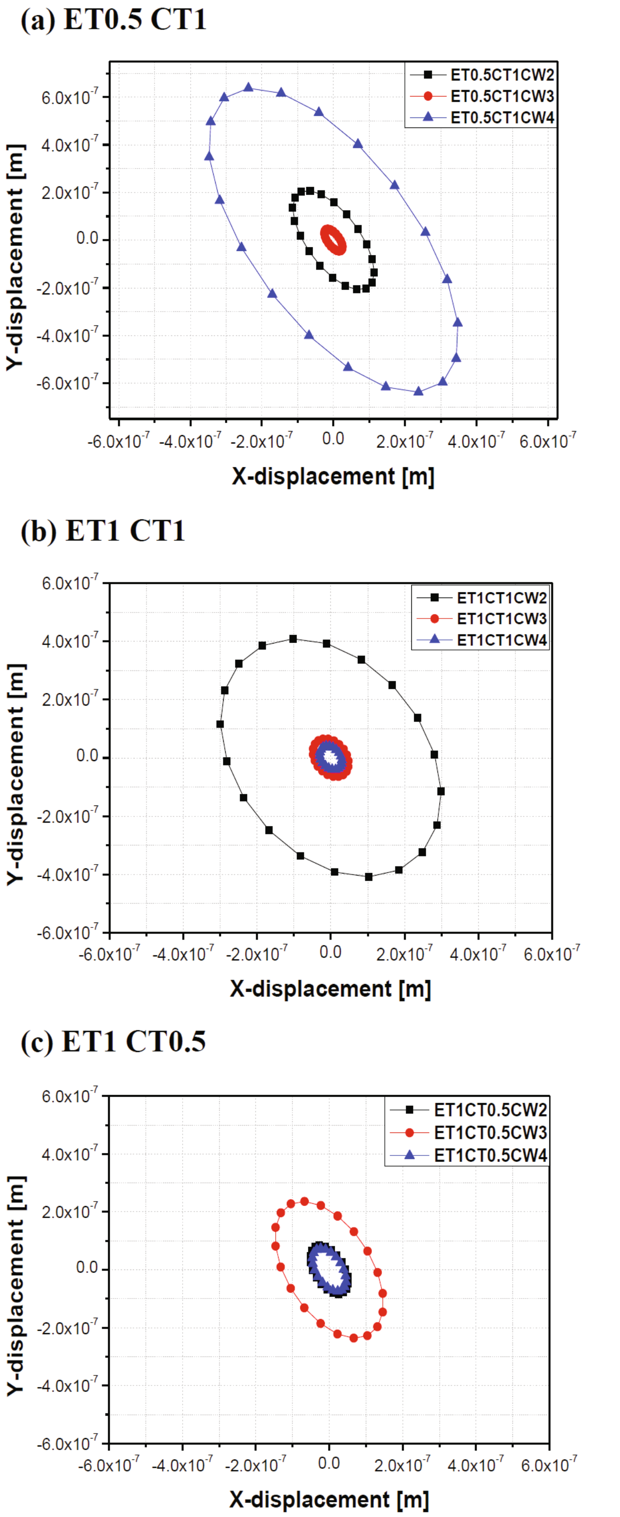


Fig. 4. (Color online) Dependence of the characteristics of the stator depending on the width of the ceramic: (a) ET0.5 CT1 CW2, 3, 4, (b) ET1 CT1 CW2, 3, 4, (c) ET1 CT0.5 CW2, 3, 4.

voltage was 10 V, and the elastic material and the piezoelectric ceramic were SUS304 and PZT4, respectively.

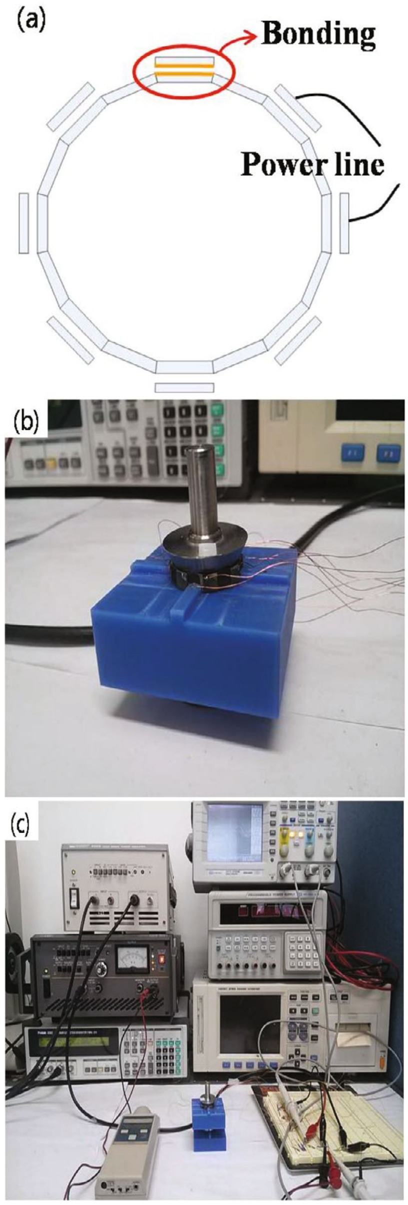


Fig. 5. (Color online) (a) Structure of the fabricated stator, (b) photo of the motor, (c) photo of the measurement setup.

IV. FABRICATION AND EXPERIMENTS

The stator ET0.5CT1CW4, which had the maximum elliptical displacement in the FEM analysis was selected and fabricated. Figure 5 shows the structure of the fabricated stator, a photo of the rotor and a motor of the measurement.

Figures 6 and 7 show the dependence of the speed and the torque on the frequency and the applied voltage. The speed and the torque of the motor were measured on the applied voltage was increased in 5V intervals from 10 V to 40 V. For stator ET0.5CT1CW4, the maximum speed and torque were obtained at a maximum voltage

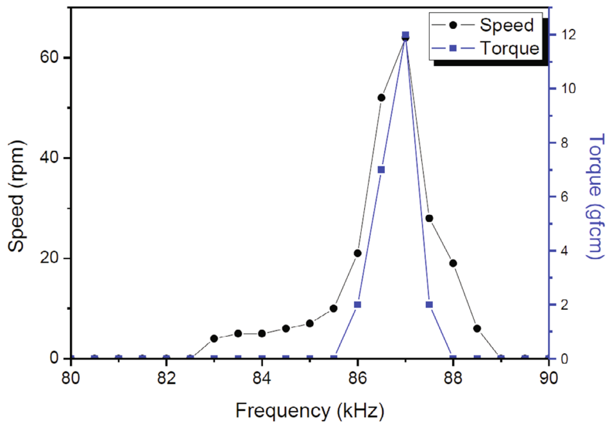


Fig. 6. (Color online) Dependences of the speed and torque characteristics on the frequency.

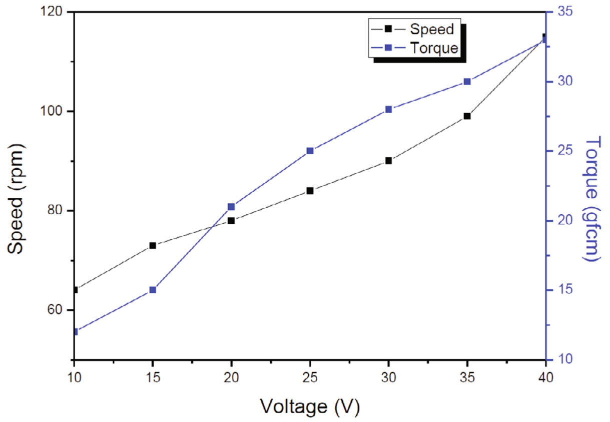


Fig. 7. (Color online) Voltage-dependences of the speed and torque characteristics.

of 40 V, where the motor had a speed of 115 rpm and a torque of 33 gfcm. The driving frequency of the model ET0.5CT1CW4 was 87 kHz.

V. CONCLUSION

In this study, a novel ultrasonic rotary motor with a hexadecagon-shaped stator was proposed. The stator of the hexadecagon ultrasonic motor was composed of an elastic ring and ceramics. The elastic ring had sixteen sides and sixteen angular points. Eight ceramics were attached on the outer surfaces of the eight sides of the ring. When the rotor of cylindrical shaft was inserted inside the ring stator, the central lines of the sixteen sides of the stator held the shaft with slight pressures (friction). This slight pressure was a preload at the motor, and it could be controlled by using the radius and the thickness of the ring. When two sinusoidal voltages that had a 90-degree phase difference were applied to each of the four ceramics, elliptical displacements of the inner surface of the ring were obtained. These elliptical displacements of the inner surface rotated the shaft rotor through friction. The proposed hexadecagon ultrasonic motor was designed and analyzed by using the finite element method (FEM), depending on the thickness and the width of the piezoelectric ceramic and elastic ring. Based on the FEM results, one model of the motor, which showed maximum displacement at the contact point was chosen and fabricated. Then the characteristics of the motor were compared with simulated results. When the motor was fabricated based on these results, the EL20ET0.5CT1CW4 model showed an angular speed of 115 rpm, an input voltage of 60 Vrms at 66 kHz. and a maximum torque of 33 gfcm. These results show that the hexadecagon-shaped ultrasonic motor can be used an actuator for an optical device that needs detailed position control. Also, it can be used in medical and portable devices with reduced size and weight.

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