Characteristics of Disk-type Linear Ultrasonic Motor for Application to x-y Stage

Kee-Joe Lim† , Seong-Hee Park*, Yong-Jin Yun*, Kee-Young Lee*, Seong-Hwa Kang, Jong-Sub Lee*** and Su-Hyun Jeong§**

Abstract - In this paper, a disk-type ultrasonic motor using a combination of radial and bending vibration modes is newly designed and fabricated. The characteristics of the test motor are also measured. By means of traveling elastic wave induced at the surface of circumference of the elastic disk, a steel bar in contact with the surface of circumference of the elastic disk bonded onto the piezoelectric ceramic disks is driven in both directions by changing the sine and cosine voltage inputs. The stator of the motor is composed of two sheets of piezoelectric ceramic disks to bond onto both surfaces of an elastic disk, respectively. As a result, the diameter of the elastic body is increased and the resonant frequency is decreased. The resonant frequency of the stator is about 92 kHz, which is composed with piezoelectric ceramic disks of 28 mm in diameter and 2 mm in thickness, and an elastic body of 32 mm in diameter and 2 mm in thickness. A driving voltage of 20 Vpp produces 200 rpm with a torque of 1Nm and an efficiency of about 10 %.

Keywords: Complex vibration mode, Disk-type linear USM, X-Y stage

1. Introduction

Recently, demand for the precision motor has increased in the optics and semiconductor industries. However, the conventional electromagnetic motor has some limitations in regards to its resolution and size. As such, a USM (ultrasonic motor) may be one of the candidates suitable for these applications. Various USMs have already been developed and used in specific applications [1, 2].

Compared with the electromagnetic motor, the USM has many advantages as follows; low profile, low power consumption, simple structure, no reduction gear, low speed at high torque, high controllability (high resolution), and so on. But, the conventional USM has some problems because the structure of the stator is complex. That is, the elastic body composed of the stator generally has the projector to enlarge the displacement in case of plate-type or ring-type USM. These kinds of stators are very complex and expensive [3-5]. A novel linear USM is designed for application to the X-Y stage or Z stage in this paper, and it is focused on eliminating the projector of the conventional linear USM. Also, a newly designed USM is fabricated and its characteristics are measured.

2. Principle of operation

The structure of the newly proposed USM is very simple as shown in Fig. 1. Its stator is composed of two sheets of piezoelectric ceramic disks and an elastic disk. Two sheets of the piezoelectric ceramic disks are bonded onto both the upper and lower surfaces of the elastic disk, respectively. The poling direction of each piezoelectric ceramic is opposite and normal to the stator face. In practical terms, how to generate an elliptical motion of a given point mass at the surface of the stator in the USM is a significant issue. As the input voltages with a phase difference of 90 degrees are simultaneously applied to each of the piezoelectric

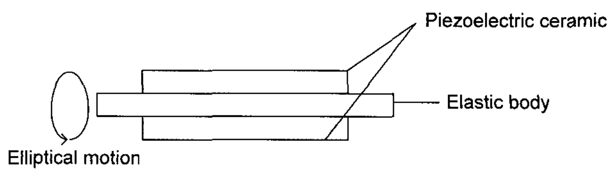

Fig. 1 The structure of the proposed USM

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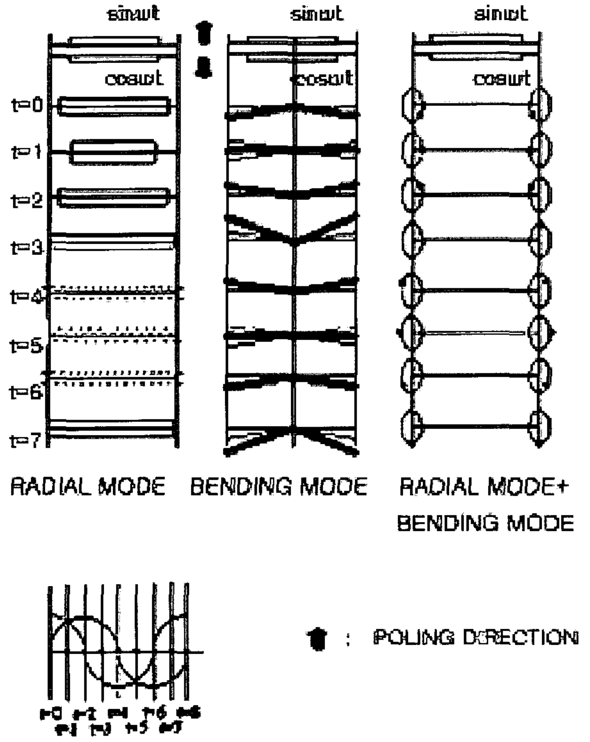
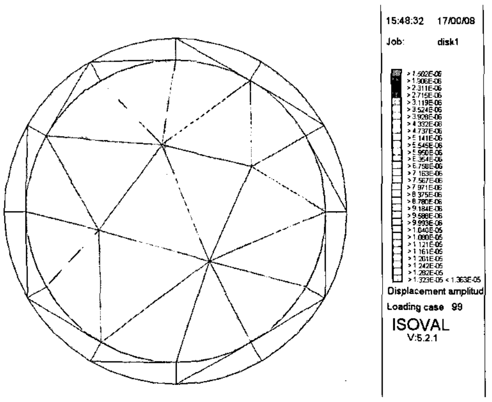
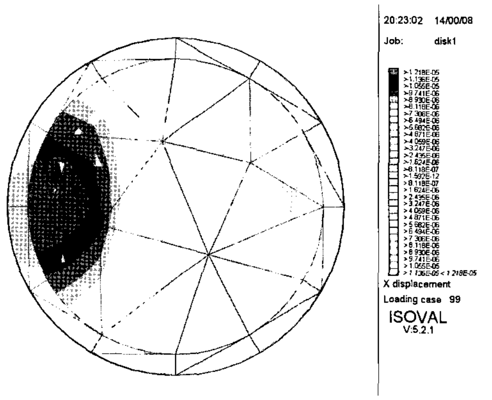


Fig. 2 The driving principle of the proposed USM



(a) The displacement of Z axis



(b) The displacement of X axis

Fig. 3 The color index of displacement induced in the stator

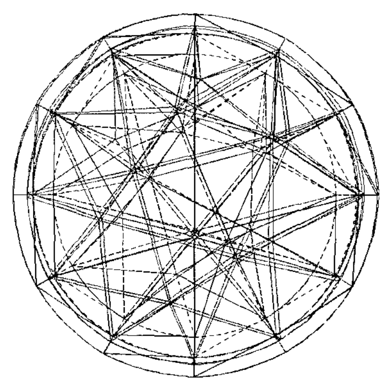


Fig. 4 The result of displacement analysis

ceramics of the stator, a combination of two modes of vibration such as the radial extensional vibration and the bending vibration forms an elliptical displacement at the surface of the circumference of the stator's elastic disk.

Fig. 2 shows the elliptical motion at the surface of circumference of the stator's elastic disk according to the time. When t=0, sinωt is zero and cosωt is maximum, so that the piezoelectric ceramic plate applied to sinωt is not deformed, but on the other hand the piezoelectric ceramic plate applied to cosωt is contracted in the radial direction because the direction of the electric field is opposite to the polarization direction. Accordingly, the stator is also bent down. As radial and bending vibrations are simultaneously generated in the stator, the position of a specific point mass on the surface of the stator at this time is marked as a dot in Fig. 2. When t=1, the amplitude of sinωt and cosωt is identical, so that the piezoelectric ceramic plate of sinωt is contracted in the radial direction and the piezoelectric ceramic plate of cosωt is also contracted because polarization direction is opposite. Accordingly, the stator is maximally contracted in the radial direction without bending. And the position of a specific point mass is also marked as a point in Fig. 2. We can see that the motion of a specific point mass on the circumference of an elastic disk shows an elliptical movement during a period as shown in the figure. A cylindrical rod is able to rotate if the rod is in contact with the circumference face of the elastic disk. The phase of input voltage also changes the rotation direction.

3. Vibration analysis

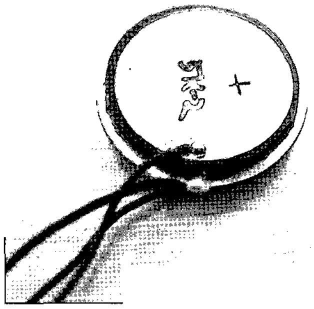
As indicated in Fig. 2, the proposed USM in this paper is driven by a combination of radial and bending vibration modes. FEM (Finite Element Method) software, manufactured by Mag. soft is used to analyze the vibration mode of the USM. Fig. 3 presents the color index of the displacement of x axis and z axis induced in the stator of 32 mm in the outer diameter. As shown in Fig. 3 (a) and (b), the stator is vibrated to the bending and radial extensional mode, respectively. The result of displacement analysis is indicated in Fig. 4. The solid line and the dashed line indicate the displaced pattern and original pattern, respectively. From these figures, we can see that a combination of two displacement modes such as radial and bending mode is generated in the stator.

4. Fabrication of motor and measurements of its performance

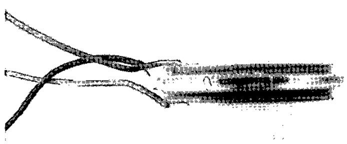
Piezoelectric ceramic is fabricated by $0.9(Pb(Zr_{0.51}Ti_{0.49})O_3)$ - $0.1(Pb(Mn_{1/3}Nb_{1/3}Sb_{1/3})O_3$ composition in order to make the USM used in this paper and its process is the conventional method. Its piezoelectric and dielectric properties are listed in Table 1. Piezoelectric ceramic is fabricated to a circular disk-shaped plate of 28 mm in diameter and 2 mm in thickness.

Table 1 Piezoelectric and dielectric properties of PZT-PMNS ceramic

Electro-mechanical coupling factor, kr	58[%]
Mechanical quality factor, Qm	1500
Piezoelectric constant, d33	340[pC/N]
Frequency constant, Np	2100
Dielectric constant	1300



(a) Top view



(b) Side view

Fig. 5 Photograph of the fabricated stator

A circular disk-shaped elastic body of 32 mm in diameter and 2 mm in thickness is made of stainless steel. A piezoelectric ceramic plate is bonded onto both faces of the elastic body by epoxy in 120°C for 20 min. The lead wires are bonded by the conducting paste. Fig. 5 shows the prototype of the stator. To measure the various mechanical properties, a cylindrical stainless steel rod of 6 mm in diameter is used as a rotor which is fixed by two ball bearings. As a lining material, Al_2O_3 ceramic of 0.5 mm in thickness is bonded onto the circumference face of the elastic disk in the stator by the epoxy. Fig. 6 presents the block diagram to measure the mechanical properties. The rotation speed is measured by the tachometer (M 3632, Yokogawa) and the metal block is used as the mechanical load. The block is connected to the rotor rod by a thin fabric string.

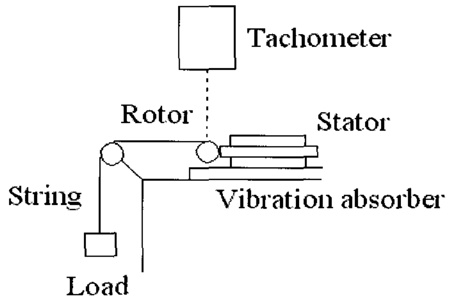


Fig. 6 The measurement block diagram of the mechanical properties

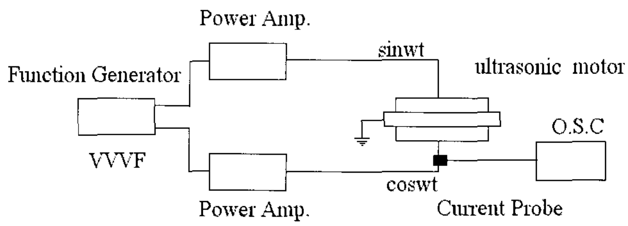


Fig. 7 The driving system of linear USM

The driving system block diagram for the USM is shown in Fig. 7. The input voltages of 90 or 270 degrees in phase difference are applied to upper and lower piezoelectric plates by function generator and power amplifier. The applied voltage and the driving frequency are adjusted by the function generator. Current and voltage are directly measured by current probe and oscilloscope.

5. Results and discussion

The changes of the rotation speed and the current of a test motor according to the driving frequency, when driven at 20 Vpp, are shown in Fig. 8. The curve indicates the typical resonance characteristics. A test motor exhibits a

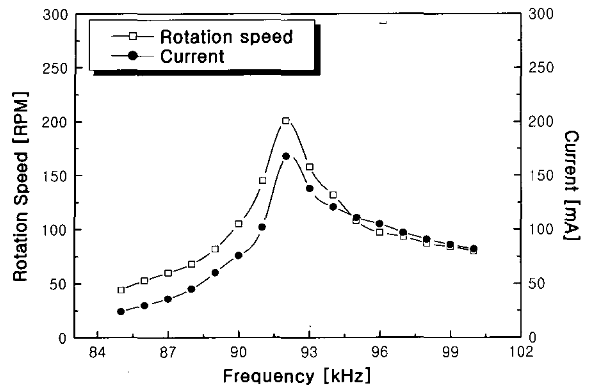


Fig. 8 The changes of the rotation speed and the current according to the driving frequency

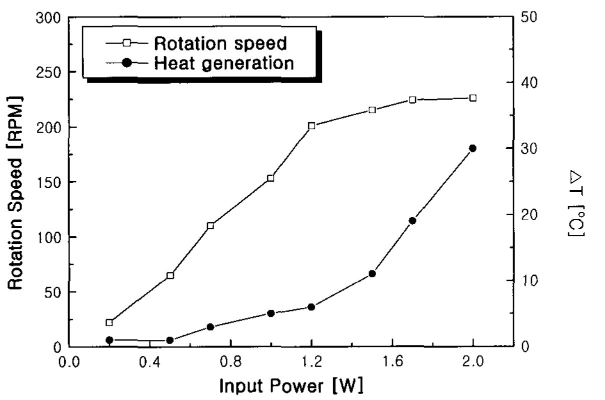


Fig. 9 The changes of the rotation speed and the temperature increases according to input power

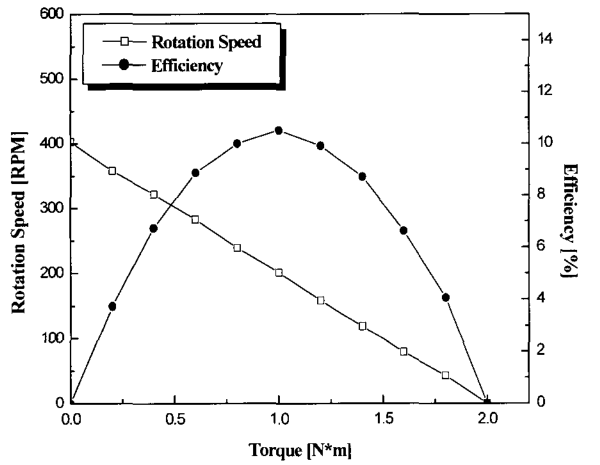


Fig. 10 Velocity and efficiency according to torque

maximum speed of about 200 rpm and a maximum current of 170 mA at 92 kHz in driving frequency. The resonance pattern is asymmetric in this figure because it may be caused by the heat generation in piezoelectric ceramic [6].

Fig. 9 depicts the changes of the rotation speed and the heat generation according to input power, when driven at 92 kHz. As input power increases, the rotation speed increases linearly until about 1.2 W, but nearly saturates more than 1.2 W. The temperature increases are nearly constant until 1.2 W in input power, but become rapidly increased over 1.2 W. These tendencies may be explained in terms of the proliferation in dissipation factor of piezoelectric ceramics more than a specific vibration velocity [7].

The changes of velocity and efficiency according to torque, when driven at 20 Vpp and 92 kHz, are shown in Fig. 10. The characteristics of velocity and efficiency vs. load torque are similar to those of general USM. The velocity is about 400 rpm at no load and the maximum efficiency is about 10% at load torque of 1 N·m.

6. Conclusion

A disk-type ultrasonic motor using a combination of radial extension and bending vibration modes is newly designed and its characteristics are discussed. The vibration mode as a function of diameter of elastic body is analyzed by the commercial finite element analysis program. The disk-type USM is composed of two sheets of piezoelectric ceramic disks and an elastic stainless steel disk, which is bonded together as a sandwich structure of P-E-P. By applying voltages with a phase difference of 90° to each piezoelectric ceramic plate, elliptical motion in the normal direction can be obtained at the circumference face of the circular disk-shaped elastic body. As a result of FEM, it is certain that a combination of radial extension and bending mode is generated at the stator of the ultrasonic motor. Also, as the diameter of the elastic body increases, the resonant frequency decreases. The resonant frequency of the stator is about 92 kHz, which is composed of a circular disk-shaped piezoelectric ceramic plate of 28 mm in diameter and 2 mm in thickness, and a circular disk-shaped elastic body of 32 mm in diameter and 2mm in thickness. As an experimental result, a driving voltage of 20 Vpp produces 200 rpm with a torque of 1 Nm and 10% efficiency. The newly proposed USM can be simpler and cheaper than the conventional USM having "teeth". Furthermore, it is available to the application of various precision machines.

Acknowledgements

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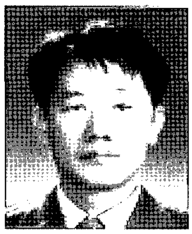

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