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disk-type 초음파모터의 특성평가

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Characteristics of disk-type linear Ultrasonic Motor

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Abstract- In this paper, 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 circumferenceof 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 disk to bond onto both surfaces of a elastic disk, respectively. As the results, the diameter of elastic body is increased, 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 %.

1. Introduction

Recently, the demand of the precision motor is increased in the fields of optics and semiconductor industries. But, the conventional electromagnetic motor has the limitation in its resolution and size. An USM(ultrasonic motor) may be one of candidates for these applications. The various USM are already developed and used in specific applications.[1, 2]
Compared with electromagnetic motor, 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, elastic body composed of the stator has generally the projector to enlarge thedisplacement in case of plate-type or ring-type USM. These kinds of stators are very complex and expensive.[3-5] A novel linear USMis designed for applying to X-Y stage or Z stage in this paper, and it is focused on eliminating the projector of conventional linear USM. Also, newly designed USM is fabricated and its characteristics are measured.

2. Principle of Operation

The structure of 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 of upper and lower surface of the elastic disk, respectively. The poling direction of each piezoelectric ceramic is opposite and normal to the stator face. In practical, it is important how to generate an elliptical motion of a given point mass at surface of stator in USM. As the input voltages with a phase difference of 90 degrees are simultaneously applied to each of the piezoelectric 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 circumference of elastic disk of the stator.

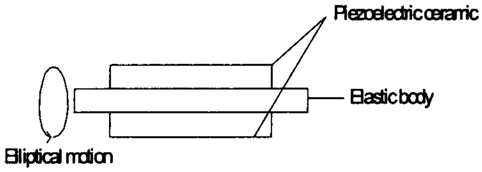


Fig. 1 The structure of the proposed USM

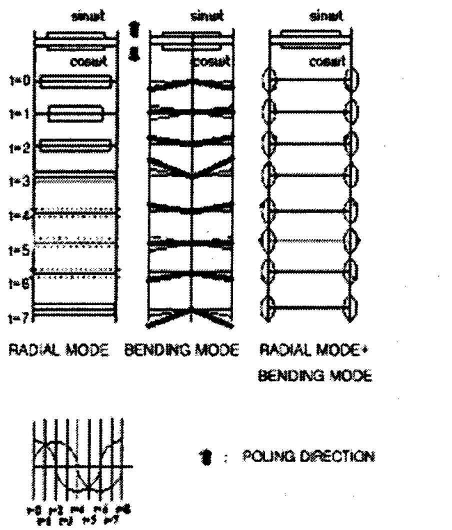
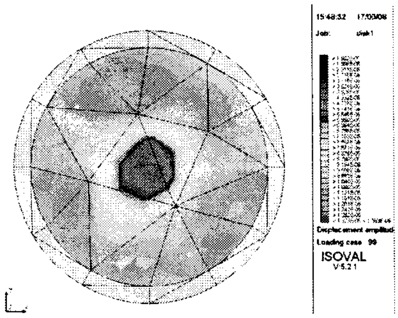
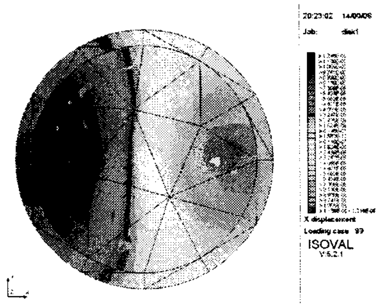


Fig. 2 The driving principle of the proposed USM

Fig. 2 shows the elliptical motion at the surface of circumference of the elastic disk of the stator according to the time. When t=0, sinwt is zero and coswt is maximum, so that the piezoelectric ceramic plate applied to sinwt is not deformed, but on the other hand the piezoelectric ceramic plate applied to coswt is contracted in radial direction because the direction of electric field is opposite to polarization direction. Accordingly, the stator is also is bent down. As radial and bending vibrations are simultaneously generated in the stator, the position of a specific point mass on the surface of stator at this time is marked as a dot in Fig. 2. When t=1, the amplitude of sinwt and coswt is same, so that the piezoelectric ceramic plate of sinwt is contracted in radial direction and the piezoelectric ceramic plate of coswt is also contracted because polarization direction is opposite. Accordingly, the stator is contracted to maximum in 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 contact with the circumferences face of the elastic disk. The phase of input voltage also changes the rotation direction.



(a) The displacement of Z axis



(b) The displacement of X axis

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

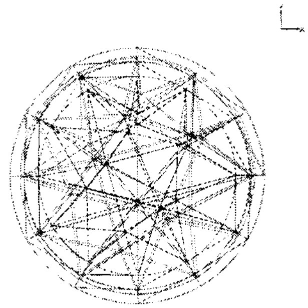


Fig. 4 The result of displacement analysis

3. Vibration Analysis

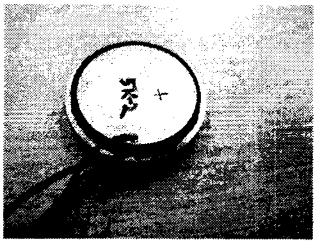
As shown in Fig. 2. the proposed USM in this paper is driven by a combination of radial and bending vibration mode. FEM(Finite Element Method) software, manufactured by Mag. soft is used to analyze the vibration mode of USM. Fig. 3shows the color index of the displacement of x axis and z axis induced in the stator of 32 mm in outer diameter. As shown in FIG. 3(a) and 3(b), the stator is vibrated to the bending and radial extensional mode, respectively. The result of displacement analysis is shown in Fig. 4. The solidline and the dashed line indicate the displaced pattern and original pattern, respectively. From these figure,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 & measurements

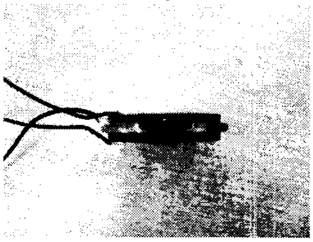
Piezoelectric ceramic is fabricated by $0.9(Pb(Zr_{0.51}Ti_{0.49}) O_3)$-$0.1(Pb(Mn_{1/3}Nb_{1/3}Sb_{1/3})O_3$ composition in order to make USM used in this paper and its process is the conventional method. Its piezoelectric and dielectric properties arelisted in Table 1. Piezoelectric ceramic is fabricated to 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 The 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. Piezoelectric ceramic plate is bonded onto both faces of 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 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 lining material, Al_2O_3 ceramic of 0.5 mm in thickness is bonded onto the circumference face of elastic diskin the stator by the epoxy. Fig. 6 shows the block diagram to measurethe 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 the thin fabric string.

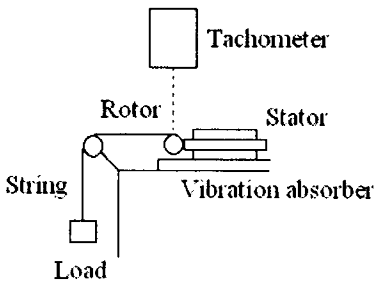


Fig. 6 The measurement block diagram of the mechanical properties

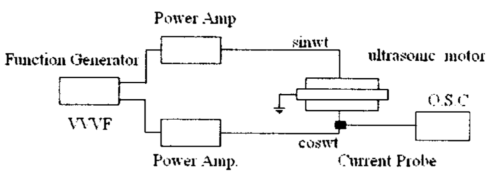


Fig. 7 The driving system of linear USM

The block diagram of driving system for USM is shown in Fig. 7. The input voltages of 90 or 270 degree in phase difference are applied to upper and lower piezoelectric plates by function generator and power amplifier. The applied voltage and the driving frequency areadjusted by 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 shows the typical resonance characteristics. A test motor exhibits a 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]

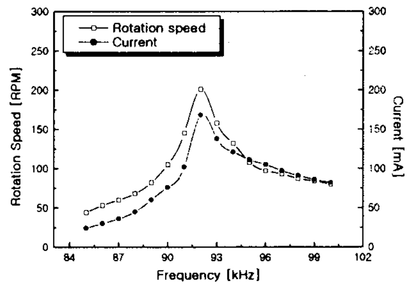


Fig. 8 The changes of the rotation speed and the current according to the driving frequency

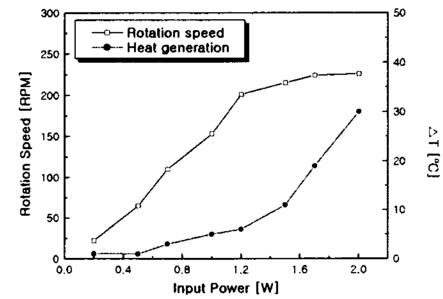


Fig. 9 The changes of the rotation speed and the temperature increases according to input power

Fig. 9 shows 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 rapidly increased over 1.2 W. These tendency may be explained in terms of the proliferation in dissipation factor of piezoelectric ceramics morethan a specific vibration velocity.[7]

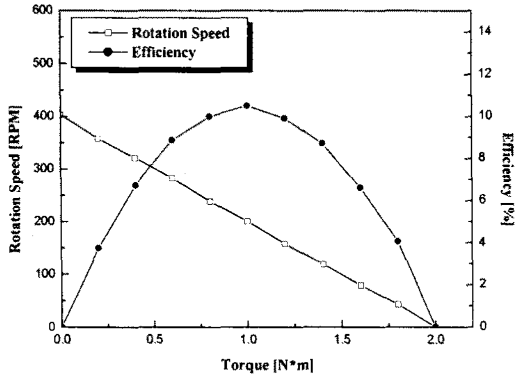


Fig. 10 Velocity and Efficiency according to torque

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 Nm.

6. Conclusion

A disk-type ultrasonic motor using a combination of radial extension and bending vibration modes is newly designed and discussed its characteristics. The vibration mode as a function of diameter of elastic bodyis analyzed by commercial finite element analysis program. Disk-type USM is composed of two sheets of piezoelectric ceramic disk and an elastic stainless steel disk, which is bonded with together tosandwich 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 circular disk-shaped elastic body. As a result of FEM, it is sure that a combination of radial extension and bending mode is generated at the stator of ultrasonic motor. Also, as the diameter of elastic body increases, the resonant frequency decreases. The resonant frequency of the stator is about 92 kHz, which is composed of circular disk-shaped piezoelectric ceramic plate of 28 mm in diameter and 2 mm in thickness, and circular disk-shaped elastic body of 32 mm in diameter and 2mm in thickness. As a experimental result, a driving voltage of 20 Vppproduces 200 rpm with a torque of 1 Nm and 10 % in efficiency. The newly proposed USMcan be more simple and cheaper than the conventional USM having "teeth". And it is available to the application for the various precision machines.

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