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Design of the Semi-Elliptical Ultrasonic Motor
半楕円形の超音波モータの設計

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1. Introduction

In the author's past study, a linear ultrasonic motor with an elliptical shape stator was developed, as shown in Fig.1. The motor is mainly composed of the elliptical stator, the slider, the pre-load spring, the support mechanism, and the encoder. In Fig.2(a), there exists a contact point in the top of the stator for the frictional interaction between the stator and the slider. In addition, a fixture is set at the position between the two piezoelectric actuators to fix the stator on the support mechanism. Due to the symmetrical shape of the elliptical stator along the horizontal and vertical axes, the elliptical ultrasonic motors have a compact structure with the high stiffness. A good performance is measured in our prototype [1,2].

However, the support mechanism of the motor is still too complicated for some miniaturized applications. To simply the elliptical ultrasonic motor, the elliptical stator and the support mechanism are considered to be simplified as a compact design of the semi-elliptical stator, as shown in Fig.2(b). The semi-elliptical stator is composed by two multilayer piezoelectric actuators, PZT1 and PZT2, clamped in a semi-elliptical elastic body. Two orthogonal mechanical vibration modes of the stator can be excited to generate elliptical motion on the stator surface.

2. Operating Principle

The motor developed in this study is a double mode type ultrasonic motor, so two orthogonal mechanical vibration modes of the stator are essential to be excited for the generation of elliptical motions on the contact point. In the semi-elliptical stator, the normal vibration mode and the tangential vibration mode of the stator are orthogonal at the contact point and shown in Fig.3(a)(b). Based on our design, these two vibration modes degenerate at the proper dimensional ratio for coincidence of the two frequencies.

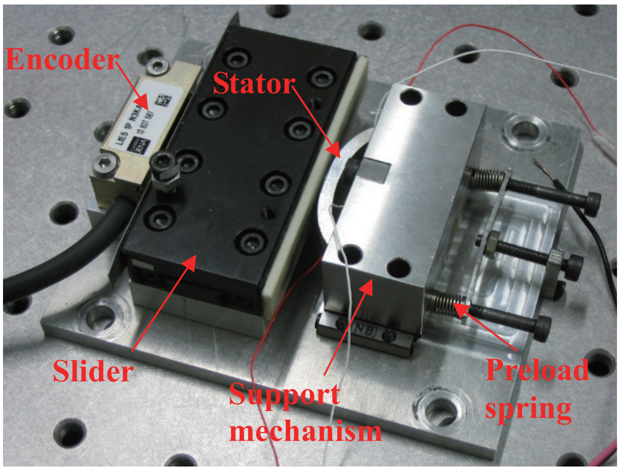
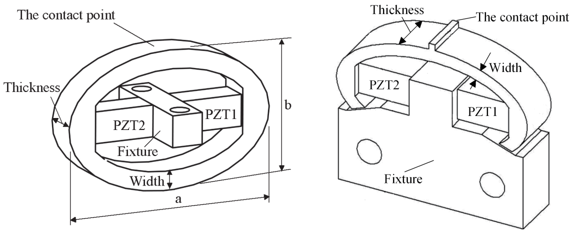
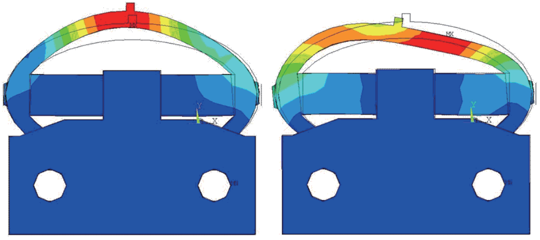


Fig. 1 Photograph of the elliptical ultrasonic motor.



(a) The elliptical stator (b) The semi-elliptical stator
Fig. 2 The elliptical and semi-elliptical stators.


(a) Normal mode (b) Tangential mode
Fig. 3 Vibrational modes of the semi-elliptical stator.

The stator can be excited by applying the same frequency voltages with 90° phase difference on the piezoelectric actuators to produce an elliptical motion on the contact point, as shown in Fig.4. The elliptical motions generated by the normal and tangential modes are explained below. The sequence of the displacement on the contact point of the stator for a vibration cycle is shown in Fig.5(A)-(H). Fig.5(A) corresponds to a temporal phase $\theta=0$, the contact point move to the upper left when PZT1 is applied with the maximum negative voltage and PZT2 is applied zero voltage. Fig.5(C)

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corresponds to a temporal phase θ=π/2, the contact point move to the lower left when PZT1 is applied zero voltage and PZT2 is applied with the maximum positive voltage. Fig.5(E) corresponds to a temporal phase θ=π, the contact point move to the lower right when PZT1 is applied with the maximum positive voltage and PZT2 is applied zero voltage. Fig.5(G) corresponds to a temporal phase θ=3π/2, the contact point move to the upper right when PZT1 is applied zero voltage and PZT2 is applied with the maximum negative voltage. Thus, the elliptical trajectory rotates in the counterclockwise direction is a repeat of Figs.(A) to (H). In the same way, the elliptical trajectory rotates in the clockwise direction when the phase difference is -90°.

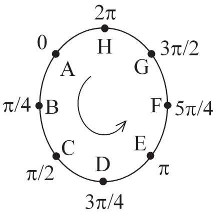

Fig. 4 Trajectory of elliptical motion

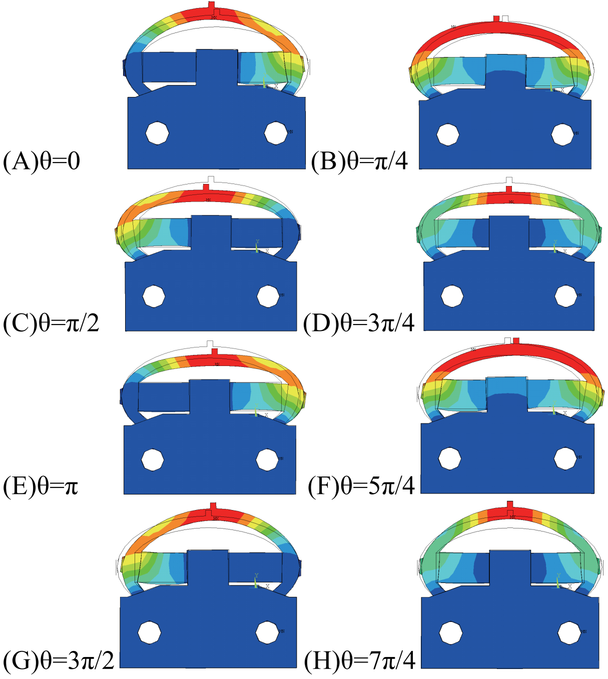
(A)θ=0 (B)θ=π/4
(C)θ=π/2 (D)θ=3π/4
(E)θ=π (F)θ=5π/4
(G)θ=3π/2 (H)θ=7π/4

Fig. 5 Trajectory of elliptical motion

3. Discussion

The geometry of the stator has been computed with the help of the finite element analysis. The dimensions of the stator's structure were determined by making the two resonance frequencies close to each other. The two modes degenerate when the dimensional ratio of major axis and the minor axis diameter is equal to 2.0. Thus, the natural frequencies of the tangential and normal modes are designed to be 19.2 kHz when the dimensions of the stator are design as 2 mm of the width and 6 mm of the thickness.

Fig.6 shows the input impedance response of the stator for a frequency range from 16 to 24 kHz. Fig.7 shows the displacement response of the normal and tangential direction on the contact point of the stator when the applied voltage is 10 Volts and the damping ratio is 0.01. The normal vibration is excited by applying the same voltages to the piezoelectric actuator, but the tangential vibration is excited by applying the inverse voltages to the actuators. Fig.7 shows that the excitation frequency at about 19.2 kHz has peaks for the normal and tangential modes.

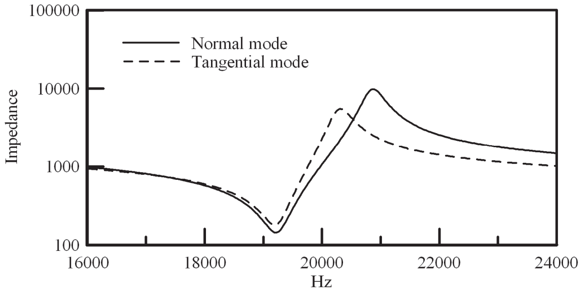

Fig. 6 Impedance curves of the stator

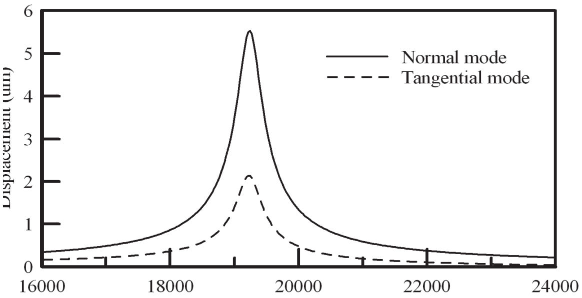

Fig. 7 Displacement response of the stator

4. Conclusion

A novel design of the semi-elliptical motor based on a double mode type ultrasonic motor is proposed and analyzed in this paper. Finite element modeling of the motor is performed. The vibration modes, the impedance and the displacement response are analyzed and discussed for the semi-elliptical motor. Some good results are obtained to understand the characteristics of this type of motors.

References

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