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A basic design of robot finger joint using multi-degree-of-freedom ultrasonic motor

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1. Introduction

Ultrasonic motors' unique advantages, such as large torque at low speed, quick response, no noise and an ability to maintain the position without electric power, have begun to arouse more attention in recent years. Several configurations for multi-degree-of-freedom (multi-DOF) motion have been proposed [1–4]. Among them, multi-DOF ultrasonic motors using only one transducer are thought to be an actuator well suited for placement at the joints of robot fingers or manipulators. The synthesis of elliptical vibration in any direction using a hybrid transducer can produce the rotation of a ball rotor in three directions. In this study, to use the multi-DOF ultrasonic motor in a robot finger, we develop a hybrid transducer with the combination of a bolt-clamped transducer and a multilayered piezoelectric element, as well as the holding mechanism of the ball rotor suitable for the motion of the robot finger.

2. Motor configuration and the principle

The structure of the stator is shown in Fig. 1. The stator consists of a bolt-clamped Langevin-type bending transducer and a cylindrical multilayered piezoelectric actuator. Two PZT piezoelectric ceramic disks 20 mm in outer diameter, 10 mm in inner diameter and 2 mm in thickness are sandwiched by a substrate and aluminum blocks with a bolt. The poling directions of the PZT disks are shown in the figure. The negative sides of the two PZT disks are connected to the substrate and the aluminum block, respectively. The positive sides' electrodes of the PZT disks are taken away. To excite bending vibration in two orthogonal directions, four bronze electrodes x, x', y and y' are sandwiched between the two PZT disks. By selecting the electrodes, the bending vibrations for two different directions are excited independently. For x-axis bending vibration, voltages with a 180° phase difference are applied to two diagonally located electrodes x and x'. The y-axis bending vibration can be excited by choosing the electrodes y and y'.

The multilayered piezoelectric actuator is employed in the motor to produce longitudinal vibration in the z-direction. The outer diameter, inner diameter and height are 19 mm, 7.3 mm, 5 mm, respectively. The advantage of the piezoelectric multilayered is that it can induce large longitudinal vibration displacements at the stator surface even when the input voltage is low and off the resonance condition. There are two aluminum blocks lying on both sides of the multilayered actuator. The outer diameters of the aluminum cylindrical blocks are 20 mm and the inner diameters are 10 mm. The thickness of the upper block is 18.4 mm, while that of the other one is 5 mm. The cylindrical substrate is made of aluminum with a diameter of 60 mm and a height of 50 mm.

Because there is no mutual coupling between the bending vibrations and the longitudinal one, we can excite each vibration independently. To rotate the ball rotor placed on the surface of the stator, two of the three orthogonal vibrations are used. X-rotation is achieved by combining the bending vibration in the y-direction and the longitudinal vibration in the z-direction with a 90° phase difference. Y-rotation is caused by the x-bending vibration and longitudinal vibration. The rotation around the z-axis is obtained by the two bending vibrations out of phase by 90°. Figure 2 shows the method of voltage application to the motor.

3. Characteristics the multi-dof motor

To make the multi-DOF ultrasonic motor practical, a prototype motor is fabricated and the driving characteristics of the motor are measured experimentally. The total height of the prototype transducer measured from the substrate surface is 33 mm. The resonance frequency is approximately 22.9 kHz when the normal load is zero. By applying voltages of 250 $V_{p\text{-}p}$ to the bending vibrators and 4 $V_{p\text{-}p}$ to the longitudinal vibrator, we obtained a 307 rpm rotation velocity in the x- or y-axis directions with a ball rotor of 25 mm diameter. The z-axis rotation velocity was 480 rpm with the voltage of 250 $V_{p\text{-}p}$ applied to the bending vibrators.

The relationship between the torque and the rotation velocity was measured at different normal loads to the rotor for the x-axis rotation. The results are summarized in Fig. 3. When the normal load was given only by the weight of the spherical rotor, the maximum torque was about 2 mNm. When the normal load increased, a maximum torque of 6 mNm was obtained. However, the surface of the stator was damaged after a long period of operation. The contact surface should be carefully chosen to improve the motor's torque and wear behavior.

Figure 4 shows the measured relationship between the frequency and the rotation velocity at different normal loads.

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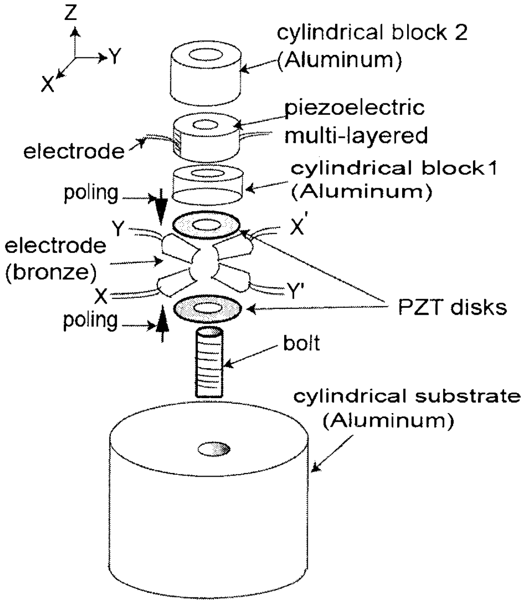
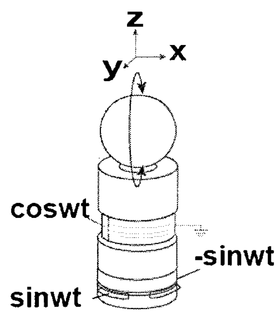
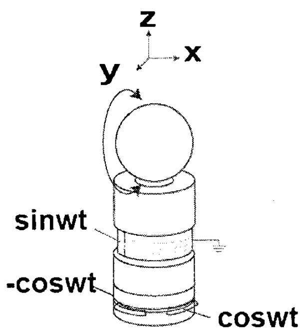


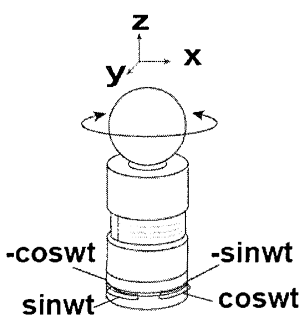
Fig. 1 Structure of the proposed multi-DOF motor.



(a) *X*-axis rotation.



(b) *Y*-axis rotation.



(c) *Z*-axis rotation.

Fig. 2 Method of rotating the ball in three directions.

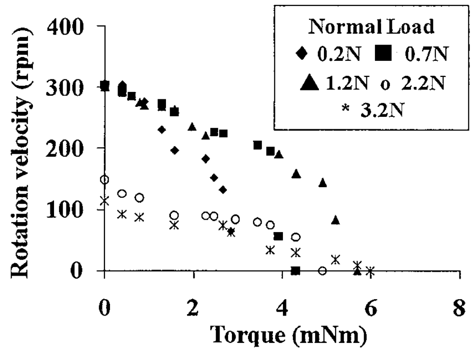


Fig. 3 Relationship between the torque and the rotation velocity.

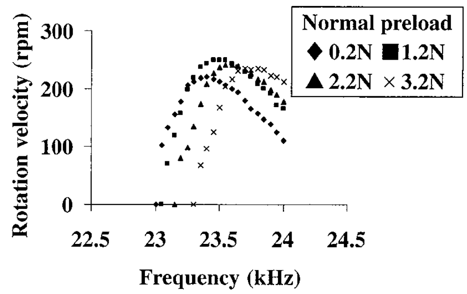


Fig. 4 Relationship between the resonance frequency and the rotation velocity.

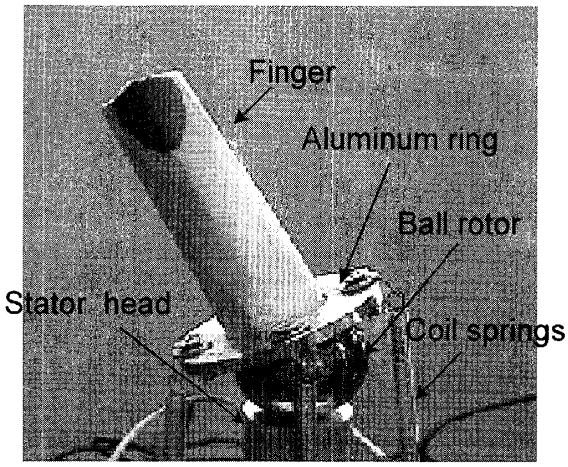


Fig. 5 Holding mechanism of the ball rotor.

The frequency of the input signals was swept from 22.9 to 24.2 kHz. The voltages of the input signals for exciting the first longitudinal vibration mode and the second bending vibration mode are 4 $V_{p\text{-}p}$ and 250 $V_{p\text{-}p}$, respectively. The phase difference of the input signals is 90°. The normal loads between the rotor and the stator was varied from 0.2 N to 3.2 N. The results show that the maximum rotation velocity is obtained when the normal load is 1.2 N, while the resonance frequency is about 23.5 kHz. The resonance frequency of the ultrasonic motor increases as the normal load increases. The frequency of the input signals should be changed accordingly to excite the motor effectively when the normal load of the motor is varied.

4. Holding mechanism

A steel ball of 25 mm diameter is pressed against the stator's top surface using four coil springs to simulate the motion of the joint as shown in Fig. 5. The springs are connected to an aluminum ring 40 mm in outer diameter, 20 mm in inner diameter and 3 mm in thickness, which is adhered to the ball. The other ends of the springs are fixed to the substrate using screws. The finger's bend-stretch motions can be obtained by the x- or y-axis rotation of the ball rotor. The movable angle ranged from $-40°$ to $45°$. The rotation directions can be controlled by changing the phase of the input signals. The z-axis rotation is also possible from $-5°$ to $5°$.

5. Conclusion

In this study, a multi-DOF ultrasonic motor was constructed to realize the motion of a robot finger joint. By using the four-spring holding mechanism, the motor can make the finger bend about 45° from the vertical position in two directions. The rotation direction can be controlled by changing the phase of the input signals. A method of improving the torque and extending the movable angle will be studied in a future work.

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References

[1] R. Bansevicius, "Piezoelectric multi-degree-of-freedom actuators/sensors," *Proc. 3rd Int. Conf. Motion and Vibration Control*, K9–K15 (1996).

[2] T. Amano, T. Ishi, T. Nakamura and S. Ueha, "An ultrasonic actuator with multi-degree-of-freedom using bending and longitudinal vibrations of a single stator," *Proc. IEEE Int. Ultrason. Symp.*, pp. 667–670 (1998).

[3] S. Toyama, S. Sugitani, G. Zhang, Y. Miyatani and K. Nakamura, "Multi degree of freedom spherical ultrasonic motor," *Proc. IEEE Int. Conf. Robotics and Automation*, pp. 2935–2940 (1995).

[4] T. Takemura, T. Maeno and N. Kojima, "Development of a bar-shapes ultrasonic motor for three-degrees of freedom motion," *Proc. 4th Int. Conf. Motion and Vibration Control*, Vol. 1, pp. 195–200 (1998).