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Study on two-dimensional ultrasonic motor using vibrations along circumference of arbitrary cross section of sphere

球の任意断面円周に沿う振動を利用した二次元超音波モータの基礎研究

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1. Introduction

Ultrasonic motors have been widely used in consumer and industrial products. However, they provide only one-dimensional movements such as rotation or back-and-forth movement. Some recent high-performance machines require very complicated movements to handle objects. For example, two-dimensional movements, not only movement in direction of any angle but also rotation, are required to direct drawing machines, microscopes, etc. Ultrasonic motors have no mechanical rotary elements, so they have no concern about contamination problem even if they are used in high vacuum chambers of process machines.

In this paper, taking stage movement for precise process machines as a target we study achieving two-dimensional movements using straight-motion ultrasonic motors. We adopt a bimorph vibrator to make a straight-motion ultrasonic motor. The circular vibrations along circumference of arbitrary cross section of a sphere are synthesized by combing independent x-, y- and z-motions. Each motion can be generated by a shaft attached to the bimorph vibrator, because the bimorph vibrator offers convex and concave deformation in specific direction. By connecting three directional shafts and controlling amplitudes and phases of driving voltages for the bimorph vibrators, we can achieve the required circular vibrations. Three pairs of the unit, connected three directional shafts with vibrators, are arranged at the apexes of an equilateral triangle. When a stage is placed on this three-unit triangle structure, we can not only move the stage in direction of any angle but also rotate it by controlling the driving voltages.

2. Bimorph vibrator

As shown in Fig.1, the bimorph vibrator consists of a metal or elastic film element sandwiched in two piezoelectric ceramic films at both sides. The polarization directions of ceramic films are determined to deform in opposite directions to each other when driving voltage is applied. So, one piezoelectric film contracts while the other expands to synchronize the applied alternating voltage, which produces convex and concave vibration as shown in the figure. To generate straight motion along each of x-, y- and z-axes like a moving piston, a shaft is attached to one side of the bimorph vibrator.

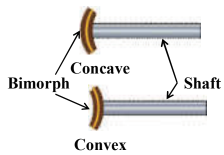

Fig. 1 Bimorph vibrator making straight movement.

3. Generation of two-dimensional movement

3.1 Fundamental motor structure

A proposed fundamental structure of two-dimensional ultrasonic motor which can move and rotate a stage in any direction is shown in Fig. 2. The stage is supported by three pairs of vibration unit located at the apexes of an equilateral triangle. The unit is constructed with perpendicularly connected three shafts, each of which is attached to one bimorph vibrator. Each unit has a tip of the z-axis shaft which supports the stage. The nine bimorph vibrators can be derived by voltages with specific amplitudes and phases. Thus the movement in direction of any angle and clockwise and counter clockwise rotation can be achieved.

In case of generating straight movement for the stage, three tips of three units vibrate along same circumference of a given cross section of a sphere. As the loci of vibrations are shown in Fig. 3(a), the cross section should be parallel to the movement direction of the stage, which can be achieved by control for amplitudes and phases of the driving voltages.

In case of generating rotation for stage, three tips vibrate along circumferences of cross sections, each of which is parallel to the rotation direction of the stage as shown in Fig. 3(b). This requires a bit complicated control for the driving voltages.

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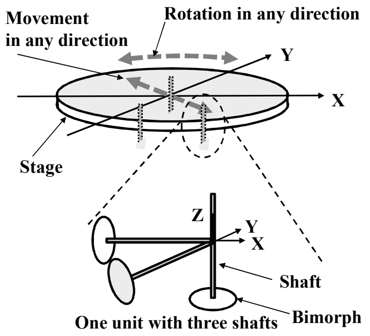
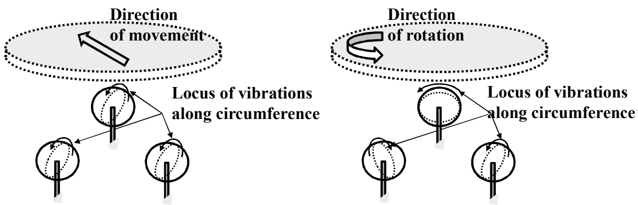


Fig. 2 Two-dimensional ultrasonic motor constructed with three pairs of unit.



(a) Straight movement (b) Rotation
Fig. 3 Generation of stage movement by controlling driving voltages.

3.2 Vibration along circumference of cross section of sphere

We investigate how to synthesize vibration of a tip along the circumference of arbitrary cross section of a sphere. Standard right-hand coordinates, (x, y, z), are assumed as shown in Fig. 4(a). The tip which is indicated by a cross in the figure rotates with angular frequency ω along the circumference of a circle illustrated by a broken line. The center of circle is same as the origin of standard coordinates. To express the tip point on the circumference with (x, y, z), we introduce concept of Euler angle. First (x, y, z) is rotated by α around the z axis, which results in (x', y', z') shown in Fig. 4(a). Then rotating (x', y', z') around x' by β leads to (x", y", z") shown in Fig. 4(b). Final γ-rotation of (x", y", z") around z" axis which corresponds to (x'", y'", z'") shown in Fig. 4(c) make it possible to express an arbitrary cross section of a sphere by (x, y, z). Therefore, the tip point which rotates on x'", y'" plane with $\theta = \omega t$ can be represented by (x, y, z) as follows:

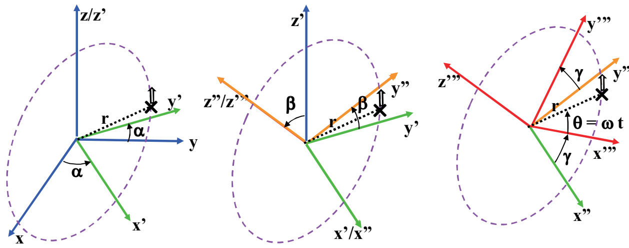
$$x = r\sqrt{\cos^2\alpha + \sin^2\alpha\cos^2\beta}\ \cos(\theta + \gamma + \varphi_x) \quad (1a)$$

$$\varphi_x = \arctan(\tan\alpha\cos\beta) \quad (1b)$$

$$y = r\sqrt{\cos^2\alpha\cos^2\beta + \sin^2\alpha}\ \sin(\theta + \gamma + \varphi_y) \quad (2a)$$

$$\varphi_y = \arctan\left(\frac{\tan\alpha}{\cos\beta}\right) \quad (2b)$$

$$z = r\sin(\theta + \gamma)\sin\beta \quad (3)$$



(a) (x,y,z)/(x',y',z') (b) (x",y",z") (c) (x'",y'",z'")
Fig. 4 Arbitrary cross section of sphere expressed by Euler angle.

4. Experimental checkup using simple model

In order to check the fundamental function of our proposed two-dimensional ultrasonic motor, we conduct a basic experiment using a simple model. Instead of a stage, we introduce a bowl-shape metal rotor whose top is supported by a sharp-edged rod like a needle as shown in Fig. 5. One unit with three shafts attached to bimorph vibrators is used. By controlling amplitudes and phases of driving voltages for x-, y- and z-bimorph vibrators, vibration of a tip of the unit along circumference of arbitrary cross section of a sphere can be achieved. Vibration forms can be checked by touching the tip to the bowl wall shown in Fig. 5 and observing rotation or swing of the bowl.

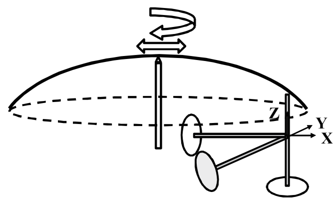


Fig. 5 Simple experimental model to check fundamental function of our proposed motor.

5. Conclusion

We have proposed a two-dimensional ultrasonic motor based on new mechanisms. Three units each of which consists of three shafts and bimorphs are arranged at the apexes of an equilateral triangle. By controlling the driving voltages, a stage on the three-unit structure can be moved and rotated in any directions. Experimental feasibility check of our proposal will be done and also presented.

References

1. H. Arimura and M. Hikita, in Proc. of Symp. on Ultrason. Electron. Vol.32, pp.243-244, 2011.