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Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 97-98
3-5 December, 2014

Study on Ultrasonic Motor to Achieve Simultaneously both X, Y Movements and Θ Rotation

ステージの X、Y 移動とΘ回転を同時に実現する超音波モーターの基礎研究

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1. Introduction

Many high-performance machines have required very complicated movements to handle objects these days. For example, not only one-directional movements with some angles but also rotations are required to direct drawing machines, stage of optical microscopes, etc. Ultrasonic motors have been widely used in consumer and industrial products. However, today's motors usually provide a single function such as a rotation or a back-and-forth movement. To achieve more complicated functions, mainly piezoelectric vibrators have been devised [1]. But recent peripheral circuit technology makes it possible to synthesize any kinds of voltage wave forms to drive piezoelectric vibrators. We have studied achieving required complex functions by combining above peripheral circuit technology with rather simple bimorph-type vibrators.

Ultrasonic motors have no mechanical rotary elements such as magnetic motors, so they have no concern about contamination problem even if they are used in high vacuum chambers of processing machines. In this paper, taking stage movement for optical microscope as an example, we study achieving both X- and Y-directional movements and Θ-angle rotations simultaneously. We adopt a bimorph-type vibrator with a shaft to make a straight-motion ultrasonic motor, which is a basic element to obtain arbitrary movement of the shaft head. The circular / elliptic vibrations are synthesized by applying required driving voltages to X-, Y- and Z-directional vibrators independently, 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, we can achieve the required forms of vibrations. Three pairs of the unit, i.e. three directional shafts with bimorph 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 to any direction but also rotate it by controlling the driving voltages.

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2. Required movements and fundamental structure

As shown in Fig. 1, an optical microscope requires X-, Y-directional movements but also Θ-angle rotations for the stage. Our proposed structure for functional motor is shown in Fig. 2(a). Three straight-motion ultrasonic motors are perpendicularly connected to form a single unit. Three units are arranged to support a movable stage illustrated in the figure. The shaft head of each unit can provide circular / elliptic motion on an arbitrary plane (x''', y''', z''') shown in Fig. 2(b). To synthesize above motion, drive voltages applied to X-, Y- and Z-bimorph are as follows:

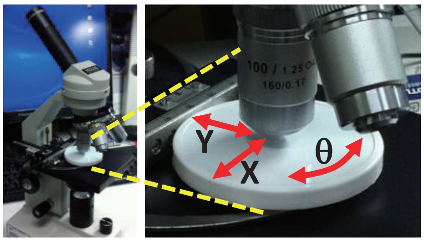
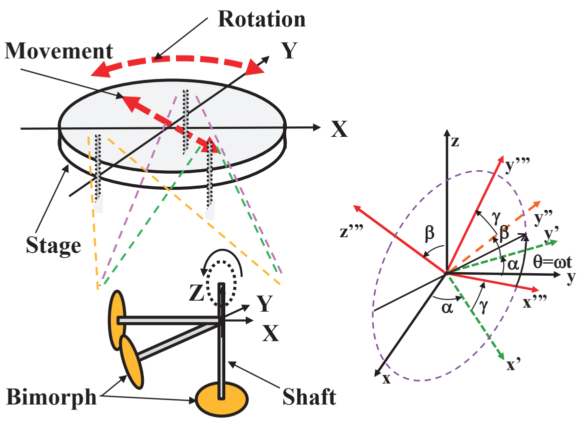


Fig. 1 Example of X-, Y-directional movements and Θ-angle rotations (Optical microscope).



(a) Fundamental motor structure to achieve required movements. (b) Shaft head's circular /elliptic motion on arbitrary plane (x''', y''', z''').

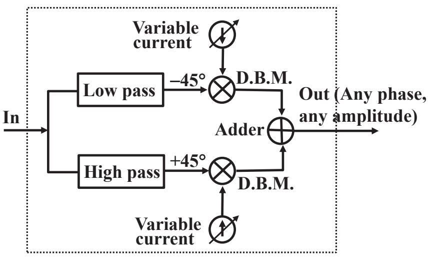
Fig. 2 Proposed structure combining straight-motion ultrasonic motors with synthesized driving voltages.

$$Vx = Vo\sqrt{\cos^2\alpha + \sin^2\alpha\cos^2\beta}\ \cos(\theta + \gamma + \varphi_x) \quad (1a)$$
$$\varphi_x = \arctan(\tan\alpha\cos\beta) \quad (1b)$$
$$Vy = Vo\sqrt{\cos^2\alpha\cos^2\beta + \sin^2\alpha}\ \sin(\theta + \gamma + \varphi_y) \quad (2a)$$
$$\varphi_y = \arctan\left(\frac{\tan\alpha}{\cos\beta}\right) \quad (2b)$$
$$Vz = Vo\sin(\theta + \gamma)\sin\beta \quad (3)$$

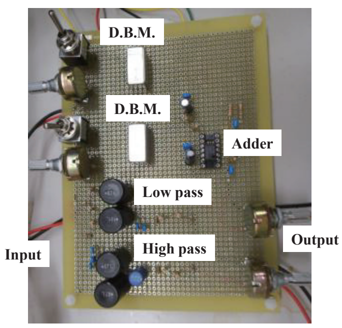
3. Synthesization of X-, Y-, Z-driving voltages

In order to obtain Fig. 2(b)'s circular / elliptic motion of the shaft heads, driving voltages given by Eq. (1) to (3) should be synthesized. Advances in peripheral circuit techniques have been remarkable, which makes it possible to provide IC-type driving circuits in near future. As the block diagram is shown in Fig. 3(a), we used rather primitive discrete circuit technique to achieve these performances. The ±45°-shift signals are obtained from input signal by low-pass / high-pass circuits. The signals with arbitrary amplitudes are obtained by D.B.M.'s (Double Balanced Mixers) and are added to provide output signal with any phase and any amplitude. A photograph of the developed functional module is shown in Fig. 3(b).

Examples of output signals at 70 kHz are shown in Fig. 4(a) to (d). In the figure, 4 phases, 0°, 90°, 180° and 270° are illustrated compared with input signals. Exactly 90° mutually shifted signals are obtained. To achieved driving voltages given by Eq. (1) to (3), any amplitude of output signals should also be synthesized. We can achieve not only any phase but also any amplitude, which can't be illustrated due to space.

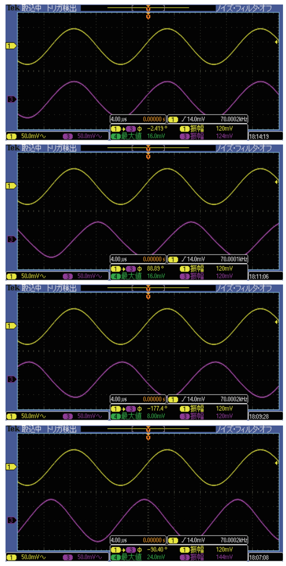


(a) Block diagram



(b) Functional module

Fig. 3 Generation of waveform with any phase and any amplitude.



(a) Upper: input
Lower: 0° output

(b) Upper: input
Lower: 90° output

(c) Upper: input
Lower: 180° output

(d) Upper: input
Lower: 270° output

Fig. 4 Output signals at 70 kHz with any phase taking input signal as standard.

4. Experimental checkup using simple model

In order to check the proposed X-, Y-directional movements and simultaneous Θ-angle rotations, we conducted 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. Only a single unit with three shafts was used but rotation of the bowl-shape metal could be observed.

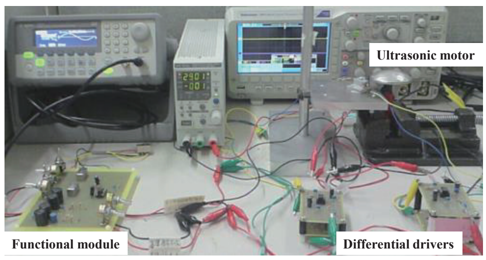


Fig. 5 Simple setup for fundamental experiment.

5. Conclusion

We have proposed an ultrasonic motor with X, Y movements and simultaneous Θ rotations. Feasibility check based on fundamental experiment showed possibility of our proposal. Detailed experimental results will be presented in the symposium.

References

1. B. Lu, M. Aoyagi, et. al, J.J.A.P. Vol. 49, 2010, pp. 07HE24-1 - 24-7.
2. Y. Nagira and M. Hikita, in Proc. of Symp. on Ultrason. Electron. Vol.34, pp.449-450, 2013.