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Generation of Rotary Motion by Circular / Elliptic Drive Synthesized with Straight-Move Ultrasonic Motors

直線動作超音波モータで合成した円/楕円運動駆動による回転機構の検討

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1. Introduction

Recently, ultrasonic motors (USMs) have been used mainly in digital cameras, cellular phones, to achieve auto-focus and zooming functions. USMs have compact sizes and can move silently compared with other conventional motors. They also have a good positioning performance. However, their applications have been limited in specific area yet. Precision devices, robots and medical machines are considered to be future applications. Many research institutions have studied new USMs and have investigated their new applications. Almost all conventional USMs are rotary-type motors. In auto-focus cameras, for example, forward and backward motions are generated using screws or similar mechanisms to convert from the rotary motion to the straight motion.

In this paper, we have studied straight-move USMs and have proposed a new reverse mechanism which generates rotary motions from straight motion of the USMs. These mechanisms are required especially in Robotics to achieve rotating hand or shoulder. The USMs which we used are developed based on new technology but their structure is very simple. The proposed mechanism can provide not only rotary motion but also possibility of new practical application of USMs.

2. Straight-move USMs

A piezoelectric bimorph consists of two or three layered structures with piezoelectric film / elastic film or piezoelectric film / elastic film / piezoelectric film. It vibrates by driving AC voltages forming convex and concave alternatively as shown in Fig. 1(a). Therefore, attached shaft to one side of the bimorph moves straightly forward and backward synchronously with convex and concave deformations as shown in Fig. 1(b). Forward and backward displacements of the shaft are very small, which requires converting mechanism to generate straight movement to rotary motion.

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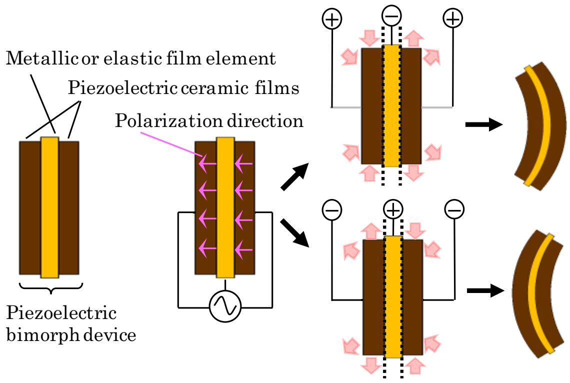
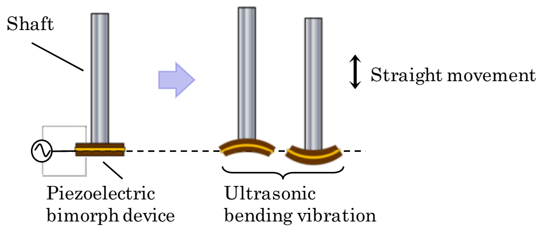


(a) Bimorph structure with convex and concave deformations.



(b) Straight movement of shaft attached to one side of bimorph.

Fig. 1 Straight-move ultrasonic motor.

3. Proposed method for generating rotary motion using straight-move USMs

3.1 Synthesization of elliptic motion from two perpendicular straight movements

First we consider synthesizing small elliptic motion using two straight movements. Two axes of an ellipse are assumed to be x' and y' as shown in Fig. 2. Introducing complex variable z', the ellipse can be represented by $z' = x'+jy'$, $x' = a\cos\omega t$ and $y' = b\sin\omega t$. We try to express this ellipse based on the original coordinates x and y by coordinate transform. The relation between z' and $z = x+jy$ can be written by $z = z'\cdot e^{j\theta}$. We can obtain the z as follows:

$$z = \sqrt{a^2 \sin^2\theta + b^2 \cos^2\theta}\,\sin(\omega t + \varphi_x) + j\sqrt{a^2 \sin^2\theta + b^2 \cos^2\theta}\,\sin(\omega t + \varphi_y) \quad (1a)$$

$$\varphi_x = \tan^{-1}\left(\frac{b\sin\theta}{a\cos\theta}\right) \quad (1b)$$

$$\varphi_y = \tan^{-1}\left(\frac{a\sin\theta}{b\cos\theta}\right) \quad (1c)$$

So we can synthesize an arbitrary ellipse from two perpendicular straight movements along x and y coordinates.

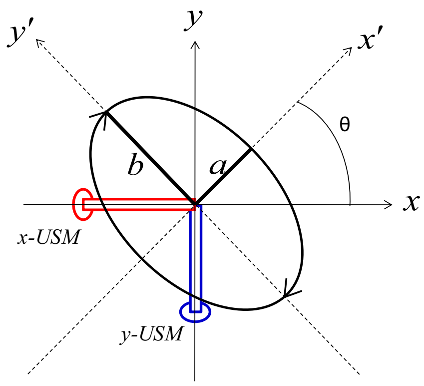


Fig. 2 Elliptic motion with x' and y' axes. The x' and y' axes are represented by x and y coordinates by rotation of angle θ.

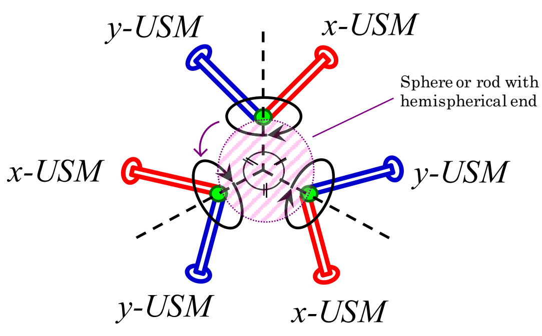


Fig. 3 Generation of rotary motion by circular / elliptic derive with three pairs of USMs.

3.2 Generation of rotary motion using three pairs of perpendicularly connected USMs

We have proposed a new configuration which can generate rotary motion with any rotation angle for a sphere and a rod with hemispherical end. Schematic illustration of our proposed structure is shown in Fig. 3. Three pairs of perpendicularly connected USMs are arranged 120° apart one another. Each of the connected USMs is symmetrical against the line from the center of the sphere or hemisphere end to the connected point. As shown in Fig. 2, two USMs, that is x-USM and y-USM, are connected perpendicularly and are droved by AC voltages with the amplitudes and phases given by the Eqs. (1). In case of Fig. 2's configuration, the θ should be determined to be π/4.

4. Investigation of driving voltages and forming optimum-shaped elliptic movements

If we make a = b in Eqs. (1), we can obtain the circular deriving movements as shown in Fig. 4(a). If we make a = 0 and b ≠ 0, the driving movements are linear as shown in Fig. 4(c), which provides no driving force to the sphere. Therefore, in order to trasfer the rotation energy most effectively we must investigate the optimum combination between a and b, that is the shape of the driving ellipse (Fig. 4(b)) taking the radius of the sphere or hemispherical end of the rod, weight of the rotor, required rotation speed and torque etc. into consideration.

(a) a = b (b) a < b (c) a =0, b ≠ 0

Fig. 4 Circular /elliptic driving voltages based on Eqs. 1' transform relations.

5. Conclusion

We have proposed a new rotation mechanism for a sphere or a rod with hemispherical end using straight-move ultrasonic motors. Three pairs of perpendicularly connected two USMs are driven by two AC voltages with different amplitudes and phases. Determination of their optimum combinations will be next problems.

References

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