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Ultrasonic Power Circulation-type Quadratic Excitation Method for improvement in torque of Coiled Stator Ultrasonic Motor

コイル状ステータ型超音波モータのトルク向上のための超音波パワー循環型直交駆動法

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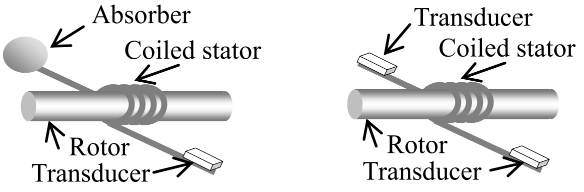
1. Introduction

In order to find medical use such as intravascular ultrasound devices (IVUS), a traveling-wave-type miniature ultrasonic motor using a helical coiled waveguide as a stator, called CS-USM (Coiled Stator Ultrasonic Motor), has been developed.[1-2] Owing to its simple structure, the CS-USM can be made smaller than the conventional ultrasonic motors. However, the torque of the CS-USM is not sufficient for practical applications. In the past driving methods of the CS-USM, the ultrasonic power is absorbed by an absorber[1)] or simply reflected at the boundary between transducer and waveguide.[2)] If the ultrasonic power generated by the transducer is recycled, the torque of the motor will be improved.

In this paper, we demonstrated an ultrasonic power circulation-type quadratic excitation method (UPC-QEM) to improve in torque of the motor. The method based on quadratic excitation has a loop structure for ultrasonic power circulation.

2. Principle

Figure 1 shows the basic form of the CS-USM. In this motor, a flexural wave is generated by the transducer and transmitted to the stator through the acoustic waveguide. When the flexural wave is propagated along the stator in the form of a helical coil wound around the rotor is driven by the elliptical motion on the surface particle of the stator. The motion principle of the motor is a well known traveling wave type ultrasonic wave motor. The ultrasonic power is absorbed by absorber in the single transducer type excitation method as shown in Fig.1 (a). The absorbed ultrasonic power becomes loss. The ultrasonic power is reflected at the boundaries between the transducer and the waveguide in the two transducer type excitation method as shown in Fig. 1 (b). In general, as the coefficient of reflection is smaller than 1, a portion of the ultrasonic power becomes loss.



(a) Single transducer type (b) Two transducers type
Fig. 1. Basic forms of CS-USM.

The basic form of the UPC-QEM is shown in Fig. 2. A propagation wave is generated by superimposing two standing waves whose phase differs by 90 degree in time and phase.[3)] The length of the waveguide loop is equal to integer multiples of the wavelength (λ) of the ultrasonic wave. The transducer excites the standing wave at the natural resonance frequency. The standing wave excited at the transducer 1 is given by

$$u_1(x,t) = A \sin kx \sin \omega t\ . \quad (1)$$

Here x, ω, k, and A represent the coordinate, the angular frequency, wave number and amplitude of the flexural wave. Similarly, the standing wave whose phase differs by 90 degree in time and phase exited at the transducer 2 is given by

$$u_2(x,t) = A \cos kx \cos \omega t\ . \quad (2)$$

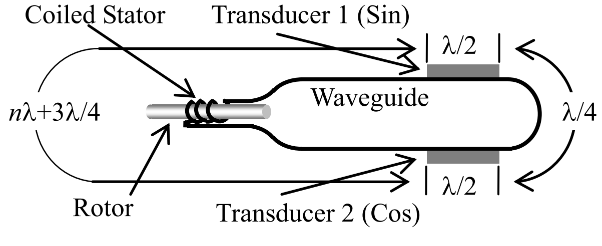


Fig. 2. Basic form of UPC-QEM.

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The traveling wave is given by

$$\begin{aligned} u(x,t) &= u_1(x,t) + u_2(x,t) \\ &= A\sin kx \sin \omega t + A\cos kx \cos \omega t. \\ &= A\cos(kx - \omega t). \qquad (2) \end{aligned}$$

If it is needed to rotate the rotor in the reverse direction, those exited signals are changed in the form from "Sin" to "Cos" or from "Cos" to "Sin", respectively.

3. Experiment

Figure 3 shows the schematic diagram of the experiment. The transducer was made of PZT (Lead Zirconate Tinanate ceramics) ceramics (Fuji Ceramics C-213, polarized in the thickness direction) of 3 mm width, 10 mm length, and 0.25 mm thickness. The k_{31} of the transducer was 34 %. Rectangular signals having amplitudes of 40 V_{PP} with a frequency of 145 kHz were applied to the PZTs. In this experiment, a stainless steel wire with a diameter of 0.28 mm and length of 65 mm was used for the waveguide. Those lengths of the each part of the waveguide were calculated with the frequency of 145 kHz and the group velocity of 1100 m/s.[4] The diameter of the rotor was 1.0 mm. The waveguide was wound around the rotor by 4 turns. The phase of the rectangular signals differ by 90 degree each other. Figure 4 shows the prototype CS-USM for used in these experiments.

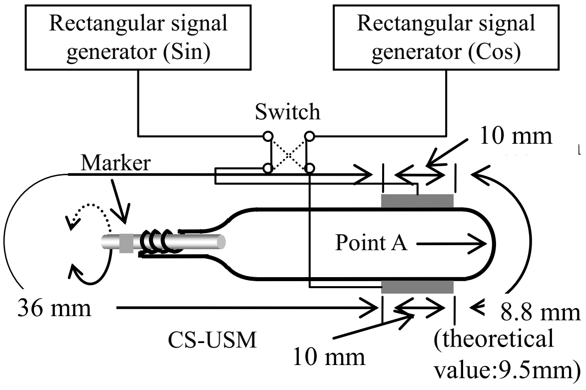

Fig. 3. Schematic diagram of experiment.

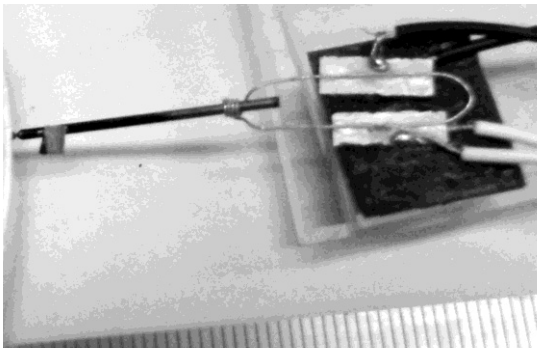

Fig. 4. Overview of prototype CS-UMS.

4. Results and discussion

Figure 5 shows the revolution speed as a function of the amplitude of the driving signal. From this figure, we confirmed that this mechanism allowed to rotate both directions. However, those revolution speeds were different. As the prototype CS-UMS is made manually, the position of those PZT were not appropriate. It is necessary to improve the assemble accuracy.

Next, to confirm the effectiveness of the loop structure, the waveguide was cut at the point A as shown in Fig. 3. Then the revolution speed at the normal direction was degreased from 2.9×10^2 to 2.3×10^2 rpm at the driving signal having amplitude of 30 V_{pp}. The torque of the motor was not measured accurately. For measurement of the torque of the motor, it is necessary to develop a measurement method for small torque. These are future problems.

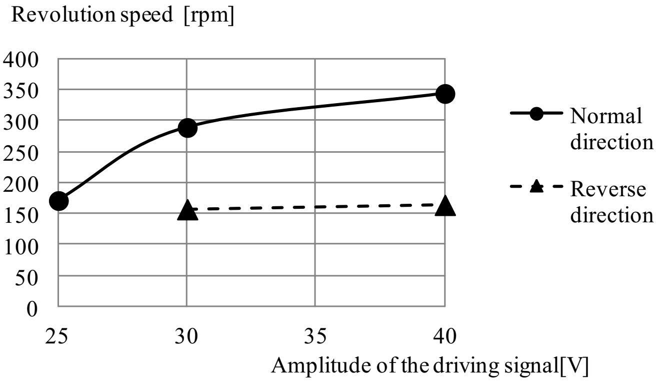

Fig. 5. Revolution speed as a function of the amplitude of the driving signal.

5. Conclusion

We demonstrated experimentally that the UPC-QEM makes the torque of the motor enlarge.

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