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A Study on Single-Phase Drive USM using Linked Twin Square Plates

連結された正方板対を用いる単相駆動型超音波モータ

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1.Introduction

The demands for ultrasonic motors (USMs) are downsizing and high output power. However, simple downsized piezoelectric devices have high driving impedance and require high input voltage. A multilayered piezoelectric structure can be driven low voltage, but deteriorates its mechanical loss popularly. Additionally, a miniature control circuit is required for the embedded devices. Therefore, the authors proposed a single-phase drive USM using the resonant mode with high excitation efficiency. For the electromechanical coupling factor of piezo-ceramics in lateral effect, k_r of in-plane isotropic vibration is almost twice larger than k_{31} of rectangular plate. Thus, the breathing mode of square plate shown in **Fig.1(a)** is considered superior vibration mode of the drive efficiency. The breathing mode of square plate potently vibrates in diagonal direction, and the vibration can rotate a rotor in one direction as shown in **Fig.1(b)**. Although it is very simple mechanism, the fixing construction is slightly difficult and popularly the motor that can rotate in both directions is required.

In this report, the square plate elements are linked as shown in **Fig.1(c)** to reverse the rotation direction by switching the driving element. It has been reported the V-shaped linked structures applied BLT and multi-layered piezo-actuator for high torque motor.[1-2] This plate type is similar in the linked structure and totally thinner than the precedent structure. The fundamental structure and driving method are explained based on FEM analysis results; additionally an experimental result of the prototype motor is presented.

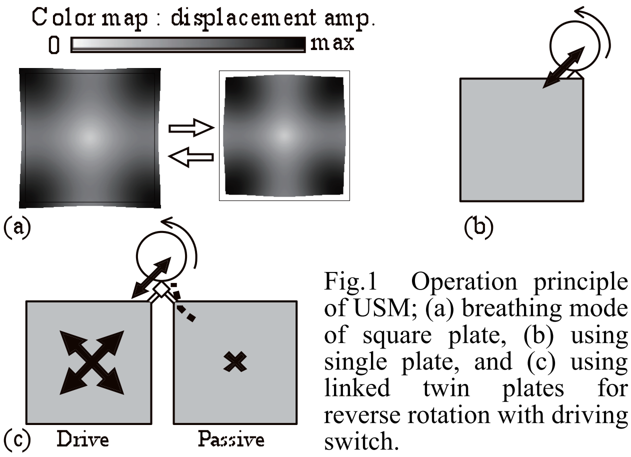

Fig.1 Operation principle of USM; (a) breathing mode of square plate, (b) using single plate, and (c) using linked twin plates for reverse rotation with driving switch.

2.Analyzed and experimental structure

Figure 2 shows dimensions of analysis and the prototype structure. The linked plate is made by brass and bonded four piezo-ceramic square plates with epoxy. The metal plate is connected to ground. The z-surface of ceramic plates have electrodes, and the poling directions are directed toward the outer electrode surface. The centers of both plates are the node of breathing mode, and are used for the fixing, to that end the centers of metal and ceramic plates are perforated. In the analysis, the internal surfaces of holes of metal plate are constrained to zero displacement.

The structural parameters are not perfectly optimized; one of those, effects of the link angle are considered in this study.

Figure 3 illustrates the experimental structure of the contacting rotor with alumina chip, and of the fixing with M2-screw and epoxy. The metal base is mounted on a linear slider, and preloaded to the rotor of 8mm in diameter made of zirconia.

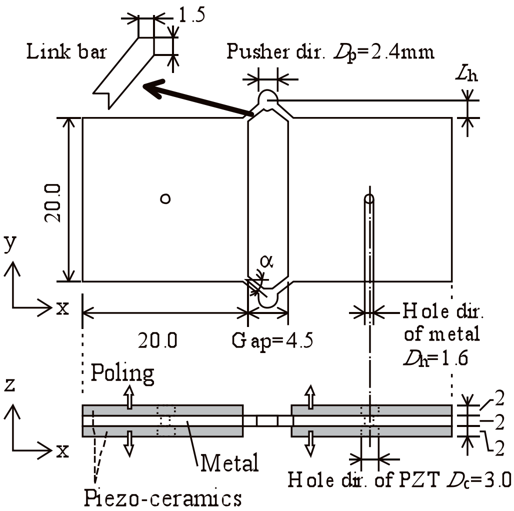

Fig.2 Analyzed model of stator vibrator.

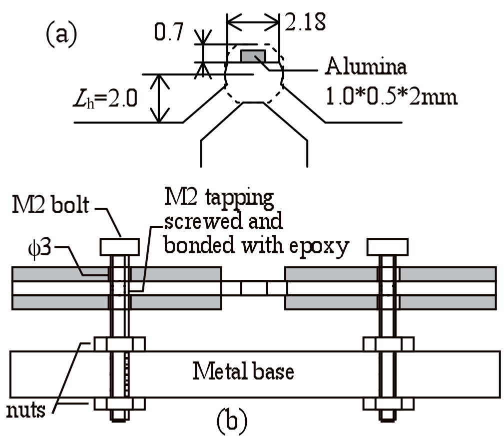

Fig.3 Experimental setup of the contact point (a), and fixing construction (b).

3.Analyzed results

The resonant vibration modes of linked structure with the breathing modes in the square elements are shown in **Fig. 4**. In this case, the left square element is assumed driving-side, and another right element is passive. However, if the passive-side

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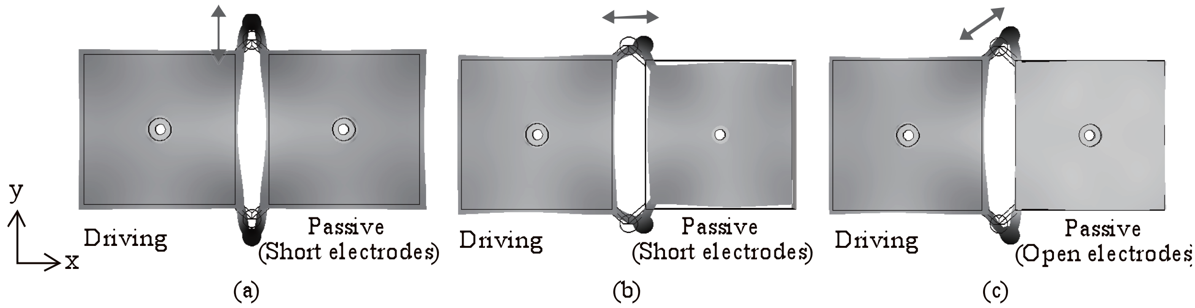

Fig.4 Resonant modes of the linked plate resonator; the modes of (a) and (b) vibrate the both sides plate, and the mode (c) does not vibrate the passive side plate and can be used to the stator of motor.

electrodes are shorted electrically, both square elements have same mechanical characteristics and vibrate as shown in Fig.4(a) and 4(b). Figure 4(a) shows the both element vibrated in the same phase, and the mode as shown in Fig.4(b) vibrates in the opposite phase. These modes vibrate the center of link in only *y*- or *x*-direction; in the result, these modes cannot be used for the single-phase drive USM. On the other hand, when the passive element is opened electrically, the elastic compliance of driving-side ceramics is s^E and of passive-side ceramics is s^D. The difference of compliances is described as $s^D = s^E(1-k^2)$, where *k* is electromechanical coupling factor. Therefore, the resonant frequency of the passive-side shifts to high frequency, and driving-side vibrates mightily and passive-side does not do so as shown in Fig.4(c); finally, the center of link moves in the both x- and y-directions to suitable for the USM. Without the fixing constraint, the almost same vibration modes are obtained.

Figure 5 shows the vibrational displacement of the center of link and the voltage step-up ratio V_2/V_1 as the functions of the link angle α. In the vicinity of α = 41deg, the displacements of u_x and of u_y in the center of link are almost same, and the displacement ratio can be adjusted by the link angle α. Simultaneously, the output voltage V_2 of the passive-side is affected by the link angle. The magnitude of V_2 means vibrational intensity of the passive-side. The high output voltage affects the surrounding, and in that condition, the vibrator is affected by the stray capacitance. Therefore, to downsize the package, the voltage step-up ratio must be small, and the link angle is limited by the permitted ratio. In the future work, other parameters have to consider obtaining the large and balanced displacement with the small output voltage.

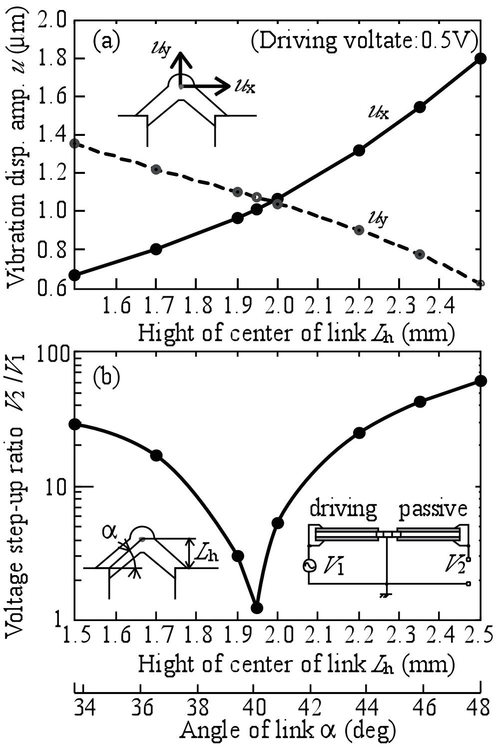

Fig.5 Analyzed results of vibration displacement amplitudes and voltage step-up ratio as the functions of the angle of link.

4.Experimental results

The prototype motor is constructed based on Fig.2-3; the link height L_h=2.0mm, and the angle α = 41.63deg. When the fixed on the base as shown in Fig.3(b) and no preloaded to the rotor, the stator vibrator has the mechanical quality factor Q_m=2058 in the resonance and the effective electromechanical coupling factor k_{eff}=37.5% measured by the resonant - antiresonant method. The voltage step-up ratio is nearly 1. The weight of stator is 41g including pins without metal base.

One of the experimental results of a load characteristic is shown in **Fig.6**, when the preload is 5N, the applied voltage is 4.5Vrms, and the phase locked target value is −15deg. Switching the driving terminal, we can obtain the reverse rotation of the almost same characteristics in the other direction of the rotation.

In this measurement, input electric power was around 1.2W, and the heat generation ΔT on the surface of the ceramics was nearly 20°C. We think that the heat generation of 20°C is a border value for the practical continuous operation; thus the loss factors must be reduced to obtain the high torque output.

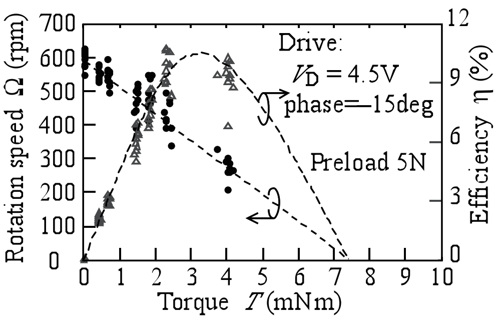

Fig.6 Experimental result of a load characteristic.

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