Miniatureized Structure of Ultrasonic Motor Using
a Linked Twin Square Plate

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1. Introduction
The ultrasonic motor (USM) using a linked twin square plate vibrator was proposed.¹² Figure 1 shows operation principle of the single-phase driving of the USM. Either-or square plate is driven with the breathing mode. Moving direction of the slider can be switched by changing the electric terminals.

The stacked plate structure has the advantage of low-profile. Therefore, the USM is required to develop the miniaturized structure with lower height.

In this report, we analyzed to design the stator vibrator with half dimensions of the first trial structure. Thickness of the ceramic and metal plates had to be modified because spurious modes affected.

2. Dimensions of the stator
Figure 2 shows dimensions and parameters of the stator vibrator. The dimensions of (a) previous and (b) miniature stators are described in Table I. The diameters of fixing-pins and ceramic-holes are same in the both stators, because the fixing rigidity has to be retained.

3. Finite element method analysis results
For suitable design of the USM, we analyzed by FEM using COMSOL Multiphysics 4.3 with following guidelines:
- Voltage step-up ratio $|V_{\text{out}}|/|V_{\text{in}}|$ must be small.
- Driving-side link must be vibrated along the diagonal direction; thus, it is desirable for $u_{xc}/u_{yc}$, defined as shown in Fig.3(a), to be almost 1.
- The in-plane displacement of the friction-edge $u_{st}$ and $u_{xt}$ as shown in Fig.3(b) have to be large.
- Conversely, the out-of-plane displacement ratio $u_{zt}/u_{yt}$ must be small.

Analyzed results of 10×10 mm² square plates models are shown in Figs.4 and 5 when the metal thickness $t_m = 1.0$ and 0.5 mm, respectively. The out-of-plane displacement ratio $u_{zt}/u_{yt}$ deteriorate strongly in some thickness conditions. It is thought that the breathing mode is affected by spurious modes as shown in Fig.6. The both models of $t_m = 1.0$ and 0.5 mm showed similar characteristics. Therefore, we selected the thinner model. When $t_m = 0.5$ mm, Eigen frequency analyzed result is shown in Fig.7. The ceramic thicknesses with large $u_{zt}/u_{yt}$ accord with the ones that the frequency of breathing mode crossed spurious modes S1 or S2.

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*Fig. 1 Fundamental operation of single-phase USM using breathing vibration mode.

*Fig. 2 Analyzed model of stator vibrator consists of a linked twin square metal plate and four piezoceramic square plates.

*Table I Dimensions of the stator. (unit: mm)

<table>
<thead>
<tr>
<th></th>
<th>$L_p$</th>
<th>$L_G$</th>
<th>$L_h$</th>
<th>$W_L$</th>
<th>$D_p$</th>
<th>$t_c$</th>
<th>$t_m$</th>
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<tr>
<td>(a)</td>
<td>20</td>
<td>4.5</td>
<td>2.0</td>
<td>1.5</td>
<td>2.4</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>(b)</td>
<td>10</td>
<td>2.25</td>
<td>1.0</td>
<td>0.75</td>
<td>1.2</td>
<td>–</td>
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</tbody>
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*Fig. 3 Definitions of the displacement at (a) center of a V-link and (b) the friction-edge.
From these circumstances, we chose two types of practical dimensions for the low-profile stator as shown in Table II (b1) and (b2). Type-(b2) has small $u_{zt}/u_{yt}$, though the total height is as thick as 3.5 mm. Another Type-(b1) has large $u_{zt}/u_{yt}$ of 4% and the voltage step-up ratio of 1.42, nonetheless the total height is only 1.9 mm.

4. Conclusions

To obtain the suitable miniaturized stator structure for $10 \times 10 \text{ mm}^2$ square plates, FEM analyzed results were shown. Although we did not reach the discovery of perfect conditions, two practical dimensions types were chosen. In a future work, the both types will be experimentally evaluated.

References