1J4-3

Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 23-24
8-10 November, 2011

Development of Compact Piezoelectric Stirrer using a Bending Vibration Mode

曲げ振動モードを用いた小型圧電攪拌機の開発

Tomoaki Mashimo[1†], ([1]Electronics-inspired Interdisciplinary Research Institute, Toyohashi University of Technology)
真下 智昭 [1] ([1]豊橋技術科学大学，エレクトロニクス先端融合研究所)

1. Introduction

A compact mixing has much potential for analytical chemistry and life science. The use of the compact stirrer has advantages such as small amounts of sample and reagent, short time reaction, lower cost and high throughput. This technology is highly needed in micro total analysis systems (μTAS) and Lab on a Chip. A number of compact mixers are reported in past ten years [1]. Main forces to disturb the liquid are given by a pressure, a temperature, and a hydrodynamics.

Advantage of using acoustic streaming for the mixing is that the mixing force transfers to a liquid through a container wall. The container sealed can be disturbed without opening and an operator can replace the containers easily.

In this study, we propose a compact stirrer using a bending vibration mode of a metallic square cuboid. There is a through hole at the center of stirrer and a liquid is filled in the hole. The simple structure of the stirrer is easy to be fabricated. When the piezoelectric elements on the vibrator sides are excited, the liquid inside is rotated by the vibration. Compared to the acoustic streaming with MHz-order frequency, the natural frequency of the metallic cuboid is much smaller and it results in reducing a heat generation and a cavitation.

2. FEM analysis

The shape of the piezoelectric stirrer is the square cuboid with the through hole. Four piezoelectric elements are bonded to the sides of the square cuboid. When AC voltages are applied to the piezoelectric elements, the stirrer obtains the mixing force by the bending mode that is a bending vibration in an axial direction of the hole. Changes in the natural frequency of the bending mode can be analyzed by finite element method (FEM) modal analysis. The finite element modeling software used is Pro/Mechanica (PTC Co.) using the adaptive p-method. Fig. 1 shows an analytic model of the metal. Its material characteristics are those of phosphor bronze. The variables of the metal are the height H, the width (side length of square) W, and the inner diameter D. In this paper, In order to verify that the liquid is stirred by the bending mode,

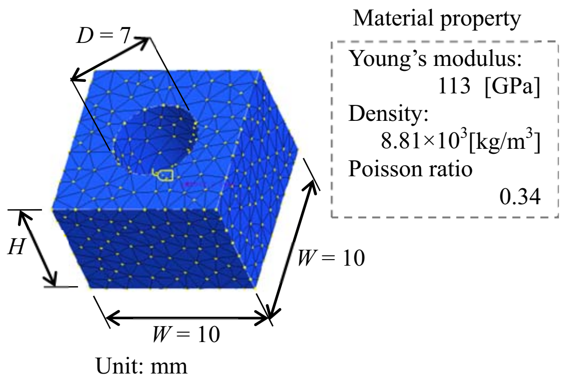
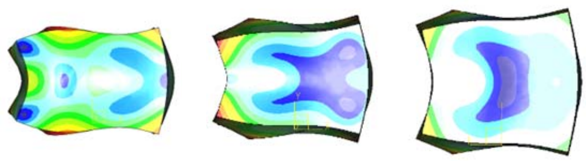


Fig. 1 FEM analytic model of the stirrer.



(a) H = 8 mm (b) H = 10 mm (c) H = 12 mm

Fig. 2 FEM analysis results for the stirrers.

three types of stirrer with different heights are examined. The height H is highly related to its natural frequency and three heights H = 8, 10, and 12 mm are selected. The other dimensions are fixed.

Fig. 2 shows the result of the FEM modal analysis. The bending modes of the stirrer with H = 8, 10, and 12 mm are observed at 176, 141, and 119 kHz, respectively.

3. Experimental

A prototype of the stirrer is built as shown in Fig. 3. The piezoelectric elements (HC-51GS, Honda electronics) have 1 mm thickness, 10 mm in width direction, and variable length H in the height direction. The piezoelectric element is polarized to both sides of the plate. One is attached to a wired and the other one is bonded to the side of the stirrer. The metallic component and piezoelectric elements were bonded by glue (one-component epoxy 2280C, ThreeBond Co.) in a thermostatic oven with a preload of approximately 20 N. The surface of the piezoelectric elements in contact with the stirrer conducts electrically to the metallic component and also to the ground.

To generate the stir, four AC voltages in phase shift by π/2 are applied around the hole. The AC voltages applied E_1, E_2, E_3, and E_4 are

$$E_1 = A\sin(2\pi f_r t) \quad (1)$$

$$E_2 = A\sin(2\pi f_r t + \pi/2) \quad (2)$$

$$E_3 = A\sin(2\pi f_r t + \pi) \quad (3)$$

$$E_4 = A\sin(2\pi f_r t + 3\pi/2) \quad (4)$$

where A is the amplitude of the AC voltages and f_r is resonant frequency to excite the bending mode. We determine that the amplitude of the voltages A is 10 V_{rms}. A wave generators (WF1974, NF Corp.) and power amplifiers (HSA4052, NF Corp.) are used to generate the AC voltages.

4. Experimental results

The natural frequencies of the stirrer are measured by an impedance analyzer (3532-50, Hioki E. E. Corp.). Fig. 4 shows the impedance of the stirrers and the arrows indicate the bending mode estimated by FEM. Steep change of the frequency can be observed at the frequency at which the bending mode of FEM. The observed frequency is slightly higher than that of the estimation by FEM.

The stirring performance of the three stirrers is examined by measuring the rotational speed of the water. The amount of the water depends on the height H of stirrer and it is approximately 3/4 of the hole volume. An aluminum powder floats on the water to measure the rotation ―Particle image velocimetry (PIV). By changing the frequency f_r of the AC voltages, the behavior of the rotational speed can be measured.

In the stirrer with H = 8 mm, the weak diffusion is observed, but a rotation cannot be measured. It is due to low vibration amplitude and low stirring force. The stirrers with H = 10 and 12 mm generate the rotation of the water. As shown in Fig. 5, the rotation of the water is observed around the frequency estimated by FEM. Positive revolution means clockwise from upside view and negative is counter clockwise. Both 10 and 12 mm stirrers show a similar behavior with clockwise and counter clockwise rotations. This reason is still unclear. Around the unidirectional rotation, the rotational direction is unstable, although the diffusion by the vibration is observed.

In the further study, we confirmed following two behavior of the stirrer: (i) the rotational speed is in roughly proportion to the magnitude of the voltages. (ii) The rotational direction is reversible when the AC voltage is changed: for example, eqs. (2) and (4) are replaced. The reversed rotational speed obtained is equal to the original speed.

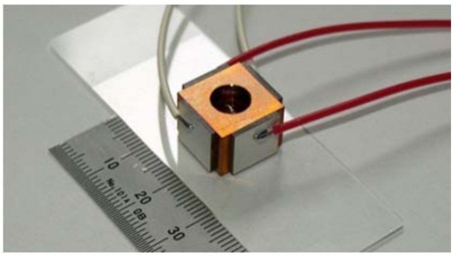
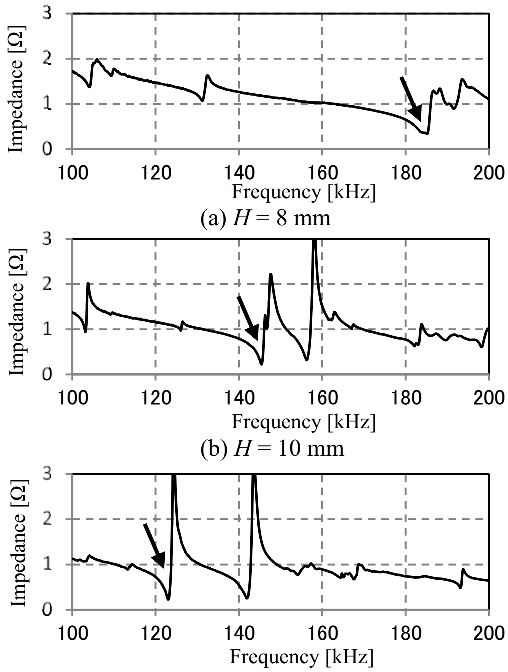


Fig. 3 Prototype of the compact piezoelectric stirrer.

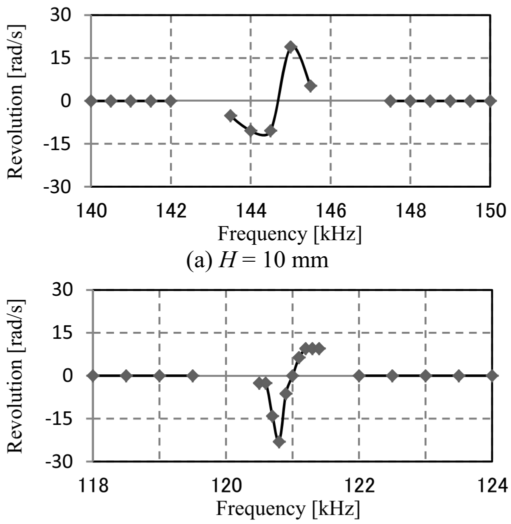


(a) H = 8 mm

(b) H = 10 mm

(c) H = 12 mm

Fig. 4 Impedance of the three stirrers.



(a) H = 10 mm

(b) H = 12 mm

Fig. 5 Experimental stirring performance (Revolution).

References

1. N. Nam-Trung and W. Zhigang, "Micromixers a review," Journal of Micromechanics and Microengineering, 15, p. R1, 2005.