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Design and Fabrication of 5 mm Tiny L1B4 Ultrasonic Linear Motor Having Up to 1.5 N Push Force

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1. Introduction

Small ultrasonic linear motors with a scale of smaller than 5 mm in transverse direction related to its moving direction may find applications in robotics fields, for example, as a driver of the robot finger or the driver of the muscle employed to facial expression. Several types of tiny ultrasonic linear motor have been reported. Among which, the L1B4 type is popular tiny motor design currently[1-3]. However, in existing ultrasonic linear motors, production of small in diameter, rapid response and large force is difficult to achieve.

In this study we aim to realize an ultrasonic linear motor that is comparable with a natural muscle from a viewpoint of direct actuation, the output force and the responses. In the first part of the paper we redesigned the structure of L1B4 motor to reduce the width below 5 mm. To obtain large mechanical output force, we constructed a L1B4 motor with 5 pieces of piezoelectric ceramics. Then several fabrication methods of the motor are investigated experimentally. In order to achieve a large output force we proposed a new holding mechanism with high stiffness.

2. Motor Configuration

On the basis of the study on miniaturizing L1B4 type ultrasonic linear motor, the prototype with good performance was redesigned. In order to obtain high performance of output force and small vertical cross size, two methods have resorted. One is put more piezo element to use and layout them effectly. Another one is change the ways of supporting the stator vibrator.

L1B4 motor has basically two types of structure. The first type of structure is shown in **Fig. 1**. It is composed of two pieces of PZT plates and have short driving tips. The second structural type is shown in **Fig. 2**. We use four PZTs to excite bending vibration and one PZT for longitudinal vibration respectively. What's more, location of PZT is also different from each other.

We built finite element models with ANSYS. Its boundary condition is free at both ends. The material of main body is duralumin and that of piezoelectric ceramics is PZT-8. We optimized the stator's structure parameters in order to match both L1 mode and B4 mode resonance frequencies. **Fig. 3** shows working vibration modes of our prototype motor. Its L1 frequency is 64.857 kHz and B4 frequency is 65.195 kHz. The size of stator is 36mm in length, 3.7mm in height and 5mm in width.

On the basis of FEM analysis of two type L1B4 motor established above, we investigated them by computer simulation. FEM analysis includes modal analysis and harmonic response analysis. Material of the stator is duralumin. Input voltage is 100 Vp-p. Frequencies are respectively 68.4 kHz and 65.2 kHz. Coefficient of sliding friction is 0.13 and static friction coefficient is 0.15.

As the simulation results of load characteristics, the relationship between output power and output thrust and the relationship between power transmission efficacy of contact surface and output thrust, with the same input voltage, output speed, thrust and power of the second type of ultrasonic motor are greater than those of the first type. We can draw a conclusion that the design of the second structural type including stator's structure, location of PZT and electromechanical conversion effect is better than that of the first type.

3. Fabrication of the Motor

Based on the designing principle of support structure, the method of fixation was discussed, analyzed and designed further to improve motor's performance. It will decrease the effect on oscillator's vibration and energetic dissipation to improve efficiency of inversion from electric energy to mechanical energy.

Four type support structures are tested by experiment. **Fig. 4** shows the trunnion fixation structure. The trunnion is connected with the holding structure at the vibration node and pre-pressure force is loaded on oscillator by the trunnion. The mechanical property of prototype system was tested. The result of experiment was bad. It had nearly no effective force and velocity. Through the mechanic anylysis of trunnion fixation, it was realized that trunnion only can restrict oscillator's swinging because of small rigidity although the trunnion loaded downward vertical force on oscillator. The action was like the effect of a torsion spring.

Elastic rubber was used to fix around the node as

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shown in **Fig. 5**. It produced pre-pressure force not only by kinetic energy of inertia mass, but also by energy of deformation in order to improve outputting performance. Through the testing result of mechanical property, fixation of elastic rubber help to improve motor's outputting performance more, comparing with fixation of trunnion. However, this kind of fixation only can load little pre-pressure force because of small rigidity and elastic rubber produces partial vibration and absorbs energy excited by piezoelectric ceramic. Therefore, the outputting performance of motor was still not well.

Considering small rigidity and energetic dissipation, elastic rubber was replaced by rigid set screw to improve outputting performance, as shown in **Fig. 6**. Comparison with the testing results of mechanical property, the velocity of the motor fixed by set screw is nearly one time more than that fixed by elastic rubber. Through experiment, with this rigid fixation, when pre-pressure force was increasing, local stress concentration and excessive bending deformation existed. That means the pre-pressure force is limited.

In order to solve the problem that the thrust decreased notably after miniaturing, the distributing flexible supporting way has been raised. It is to optimize holding structure further, combined with the study on fixation method. On the base of trunnion fixing, elastic material of suitable rigidity is used to produce vertical flexible rectrained condition, as shown in the **Fig. 7**. This distributing flexible supporting way can make use of not only kinetic energy of inertia mass, but also energy of elastic deformation to let outputting ends.

4. Conclusions

As a result, the push force / weight ratio was much larger than previous motors. The maximum push force obtained here reached approximately 1.5 N, which is 83.3 times as large as the weight of this motor's stator vibrator.

Acknowledgment
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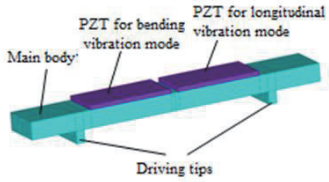

Fig. 1 Structure of the first type motor

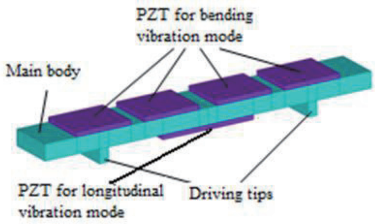

Fig. 2 Structure of the second type motor

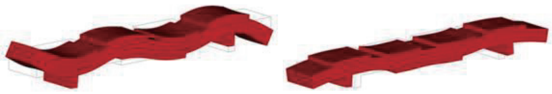

Fig. 3 FEM analysis of the second structural type of ultrasonic motor

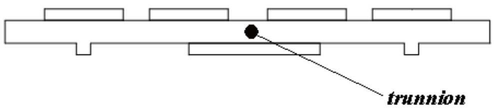

Fig. 4 Trunnion fixation

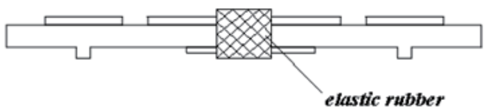

Fig. 5 Fixation of elastic rubber

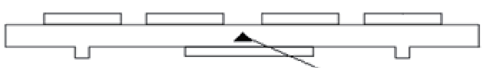

Fig. 6 Fixation of set screw

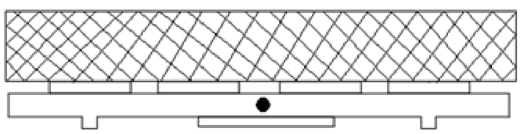

Fig. 7 Distributing flexible supporting way