2P4-10

Miniature Sandwich Type Linear Ultrasonic Motor Utilizing Traveling Flexural Waves

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1. Introduction

Small linear actuators are experiencing growing demand in precision linear drive applications, including miniature robotics, small-scale linear scanning systems, and compact optical setups [1, 2]. Electromagnetic motors are expected to replace traditional bulky compression units and extensive piping networks of air-cylinders. However, it is difficult to realize actuators with less than 10 mm in diameter with electromagnetic linear motor because the efficiency decreases rapidly with the diameter. In addition, for small drive systems, lower drive voltages and lower power consumption are highly desirable [3].

This paper introduces a miniaturized traveling-wave linear ultrasonic motor designed for efficiency in miniaturization and to operate at low voltage power consumption. The design employs two stainless steel blocks and an intermediate straight beam made of aluminum alloy to clamp two sets of piezoelectric laminated co-fired ceramics. Compared with the conventional dual Langevin sensors, the traveling wave linear piezoelectric motor proposed in this paper is smaller and more compact with a very low operating voltage which is very suitable to be integrated into a micro-small system.

2. Structure and operating principle

The proposed linear traveling wave ultrasonic motor (shown in Fig. 1) employs two stainless steel blocks and an intermediate straight beam made of aluminum alloy to clamp two sets of piezoelectric laminated co-fired ceramics. The proposed linear traveling wave ultrasonic motor, as depicted in Fig. 1, incorporates two stainless steel back blocks and an intermediate straight beam made of aluminum alloy to securely clamp two sets of piezoelectric laminated co-fired ceramics. Each ceramic set is oriented in opposite directions to induce flexural waves in the stator. At this time, the elliptical motion occurs on the surface of the middle beam of the stator, as shown in Fig.2. Sliders, held in place by bolt clamps and adjusted with springs, are moved by the traveling wave to create linear motion. The direction of movement is controlled by changing the phase difference of the excitation signal.

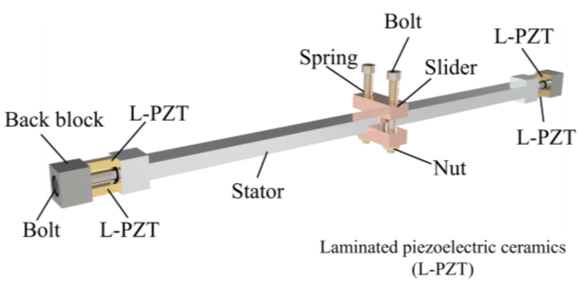

Fig. 1 Structural of the sandwich type linear traveling wave ultrasonic motor.

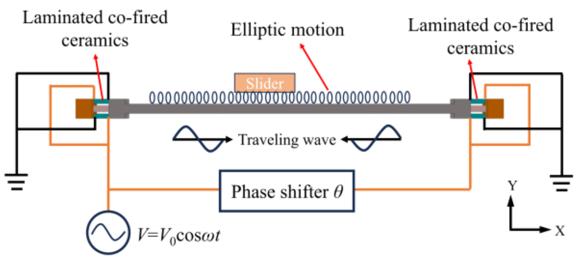

Fig. 2 Phase difference excitation and driving principle of the sandwich type linear traveling wave ultrasonic motor.

Specifically, for the principle of traveling wave generation, a type of phase-difference excitation is employed, as shown in Fig. 2. When the location in space satisfies the relationship for traveling wave generation, see literature [4] for details. When two groups of laminated piezoelectric ceramics are separately applied to a high-frequency AC signal with a phase difference of 90°, the traveling wave can be generated in the middle beam. At this time, the stator surface elliptical motion can drive the slider for linear motion.

3. Selection of piezoelectric materials

For small systems, it's important to integrate the actuator directly, which creates new demands for lower power consumption and drive voltage. A lower drive voltage means there's no need for extra booster circuits, and it also helps avoid issues with high voltage signal distortion. This paper uses piezoelectric laminated co-fired ceramics as the solution to these challenges.

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Piezoelectric laminated co-fired ceramics is a type of ceramic block in which multiple layers of piezoelectric ceramic wafers of very thin thickness are co-fired into a single unit. This type of ceramic connects multiple layers of ceramics in series mechanically and in parallel in a circuit. As a result, it produces large displacements and forces at very low voltages. However, one of the biggest problems with this approach is heat generation during high frequency excitation.

The relationship between working frequency and heat generation for several different sizes of piezoelectric laminated co-fired ceramics is presented in Fig. 3. Fortunately, it is easy to see from Fig. 3 that as the size of the piezoelectric laminated ceramic decreases, so does its rate of heat generation, which fits well with our topic of motor miniaturization. In other words, when our motor is small enough and the size of the excitation source used is very small, heat generation is acceptable.

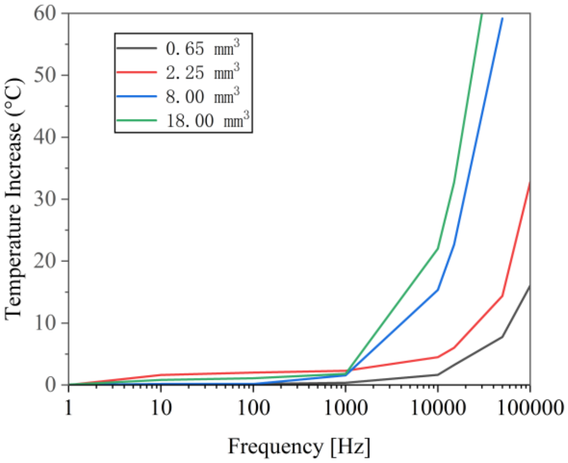

Fig. 3 Temperature rises for piezoelectric laminated co-fired ceramics of different sizes after applying a sine-wave drive voltage ranging from 0 to 150 V at the specified frequency for 10 minutes.

4. Amplitude distributions of transducer

To verify the previous conjecture, the principal prototype was built. Meanwhile, the vibration displacement distribution of the stator was tested, utilizing the out-of-plane LDV (CLV1000, Polytec, Waldbronn, Germany).

As a result of the design, the working frequency of the stator was set at 43.52 kHz. at this point, the Fig 4. displays amplitude distributions along the stator for phase differences of -90° and 90°, respectively. In these instances, traveling waves were induced in the middle section, while standing waves were activated at the ends.

In addition, the vibration displacement distribution of the stator intermediate beam at different driving voltages is also recorded, as shown in Fig. 5. We found that the amplitude of 300 V in literature [5] can be achieved at a driving voltage of only 4 V. This is very promising.

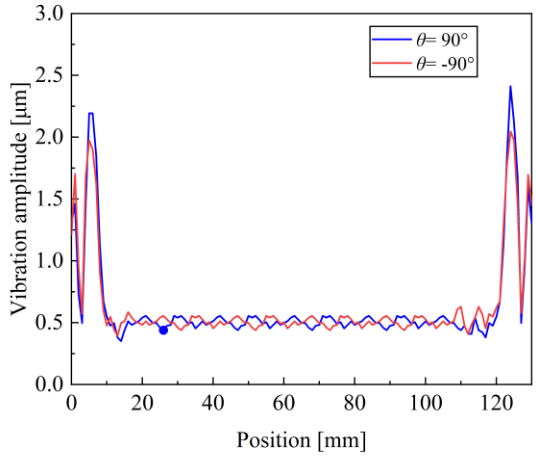

Fig. 4 Vibration distribution along the stator.

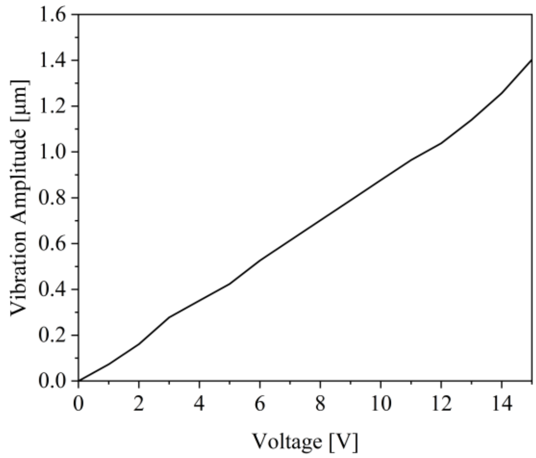

Fig. 5 Amplitude of the intermediate beam at different driving voltages.

5. Conclusions

This study introduces a novel design incorporating two sets of laminated piezoelectric ceramics sandwiched by two back blocks and an intermediate beam, facilitating the miniaturization of a linear motor to a diameter of 6 mm. The amplitude of the stator can reach 0.3 μm with 4 V excitations. The traveling wave generation principle indicates significant potential for miniaturization and integration. Future work should concentrate on Optimizations and fabrication of motors.

References

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