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Ultrasonic Linear Motor with Quadruped Stator

四脚状ステータを有する超音波リニアモータ

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1. Introduction

Ultrasonic linear motor (USLM) exhibits advantages such as high force density and linear motion with simple and compact mechanical construction compared to an electromagnetic motor [1)]. Among many types of USLM, double-sided output USLMs have achieved higher thrust than ordinal single-sided output [2)]. The double-sided output USLM has an enclosed construction in which a transducer is sandwiched between two sliders from the outside. The enclosed construction results in higher thrust and holding forces. However, since it is necessary to install two sliders outside the transducer, a relatively large space is occupied by the two sliders and preload mechanisms. Therefore, the compactness that is one of the advantages of the USLM is lost. In order to overcome this drawback, we propose a novel USLM which can achieve both enclosed construction and compactness.

2. USLM with Quadruped Stator

Figure 1 represents the proposed USLM transducer and its driving construction including a slider rod. The transducer consists of 31 effect PZT plate (C203, Fuji Ceramic Co.) and a quadruped stator made of duralumin (A2017). Those two components are bonded by a conductive adhesive (XA-874, Fujikura Kasei Co.). Each leg of the quadruped stator has 30 degrees slope and 5 mm diameter rod tangents to the slope as shown in Fig. 1. Contrary to the double-sided USLM, one slider rod is sandwiched inside the transducer, so a compact linear driving system can be realized while maintaining advantages of enclosed construction.

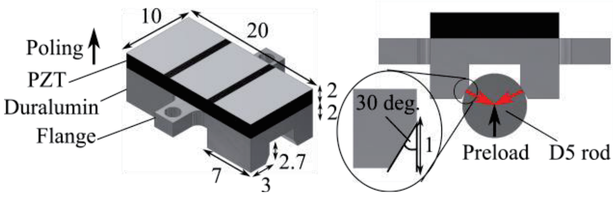

Fig. 1 Schematic diagram of the proposed USLM stator transducer

3. Driving principle

The driving principle of the proposed USLM is based on the elliptical vibrations produced by superimposing two orthogonal vibration modes. The first longitudinal mode (L1 mode) is used for exciting a driving directional vibration and the first-second bending mode (B1-2 mode) for a preload directional vibration that in this quadruped structure, the two legs on one side open and two legs on the other side close in the preload direction. In order to excite these two vibration modes, the electrode on the top of the PZT is divided into three parts A, B and B’ as shown in **Fig. 2**. Duralumin stator is electrically grounded. Driving voltage applied to these electrodes are expressed as

$$V_A = V_{L1}\sin(2\pi f t + \phi) \tag{1}$$

$$V_B = V_{B1-2}\sin(2\pi f t) \tag{2}$$

$$V_{B\prime} = V_{B1-2}\sin(2\pi f t + \pi) \tag{3}$$

where V_{L1} and V_{B1-2} are the amplitudes of the voltage for exciting the L1 and B1-2 modes, respectively. V_B and $V_{B\prime}$ are anti-phase voltage with same voltage amplitudes. Using these voltage, the L1 and B1-2 modes are superimposed with an appropriate phase difference ϕ. Elliptical vibration is then excited at each leg of the quadruped stator as shown in Fig.2 and whole motion of the transducer is like an inchworm type actuator [3)]. Consequently, the slider rod can be driven as shown in Fig. 2.

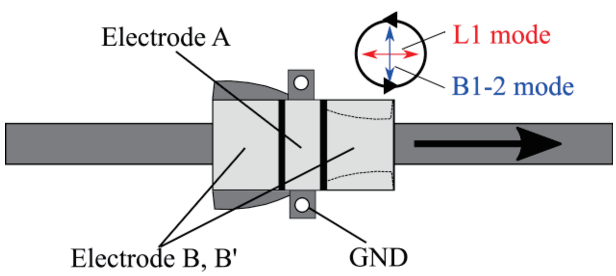

Fig. 2 Driving principle of the proposed USLM

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4. Experimental results and discussion

A prototype of the proposed USLM was fabricated and some driving experiments were conducted to confirm the driving principle. The prototype and an experimental setup are shown in **Fig. 3** and **Fig. 4**. The transducer was fixed by flanges attached to a nodal point of the two vibration modes. Then, the sliding rod (electroless nickel plated carbon steel) was pressed against the transducer by a preload spring through a bearing. The preload value applied to the sliding rod was observed by a force gauge (AIKOH RX).

Firstly, the sliding speeds under the no load condition were measured with variable driving frequency f in Eq. 1-3 by using a laser Doppler velocimeter (Canon, LV-20Z). The phase difference ϕ in Eq. 1 was set as ± 90 degrees and forward and reverse directional speeds were measured. **Figure 5** represents the measurement results. Both forward and reverse directional drives were confirmed with ϕ of ± 90 degrees. The sliding speeds reached a maximum at 83.0 and 83.1 kHz, respectively.

Secondly, the sliding speed with variable phase difference ϕ was also measured. As shown in **Fig. 6**, the sliding speed changed depending on the phase difference ϕ, and reverse driving was achieved when the phase difference ϕ exceeded 180 degrees. Based on these results, it can be considered that elliptical vibrations are excited at the drive points by superimposing L1 and B1-2 modes, as described in Fig. 2. Therefore, the proposed driving principle was confirmed.

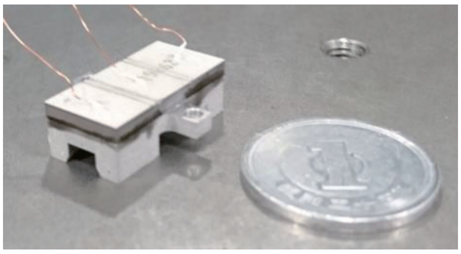

Fig. 3 Prototype of the stator transducer

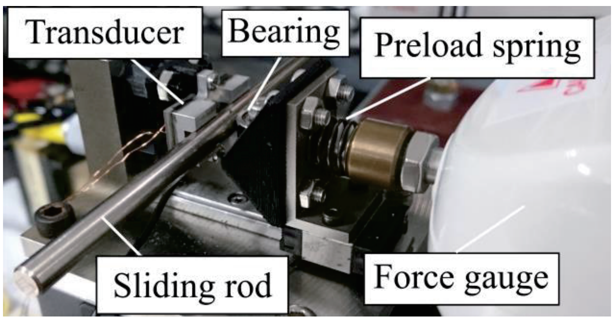

Fig. 4 Experimental setup

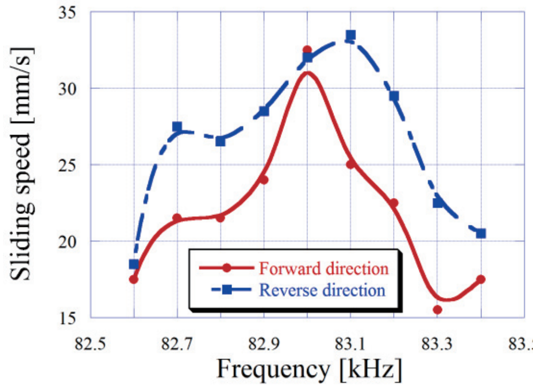

Fig. 5 Sliding speed as a function of driving frequency (driving voltage V_{L1}: 200 V_{pp}, V_{B1-2}: 200 V_{pp}, phase difference ϕ: ± 90 deg., preload: 0.16 N)

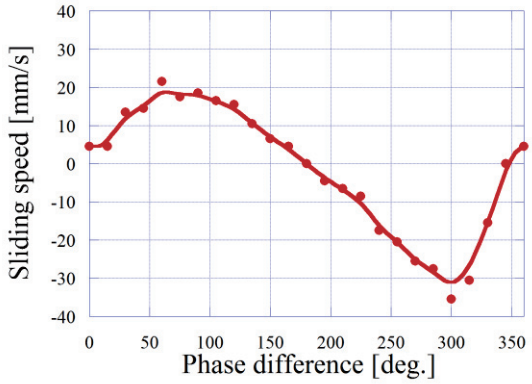

Fig. 6 Sliding speed as a function of phase difference ϕ (drive frequency: 83.0 kHz, driving voltage V_{L1} : 200 V_{pp}, V_{B1-2}: 200 V_{pp}, preload: 0.16 N)

5. Summary

In this study, we proposed a novel USLM with quadruped stator, which can realize a compact linear motion system while maintaining advantages of enclosed construction due to the slider rod inside the stator. Then, a prototype was fabricated and it achieved bidirectional drive. Thus, the proposed driving principle was confirmed via the experiments.

References

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