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Piezoelectric Linear Motor with Ultrasound Domain Tuning Fork Resonance Structure

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1. Introduction

Tuning fork resonance structure has some good properties, such as high energy conversion efficiency, large vibration amplitude and high electromechanical coupling coefficient. Because tuning fork has a non-vibration region in a wide range, the trapped-energy vibration can be used.

There are two nodes in the free-free beam. While the two ends vibrate, the middle part also vibrates in reverse phase. The effect of amplifying the amplitude of piezoelectric plate is limited. As shown in **Fig. 1**, in the sense of vibration, a tuning fork bends a long rod and only one node after bending into a U-shape. It can produce the first-order large-amplitude bending vibration similar to a cantilever beam. Moreover, the nodes of the tuning fork have neither linear nor angular displacement, and the energy loss during clamping is very small. Tuning fork is acoustic resonance, which can produce a single fixed frequency resonance with large amplitude and small attenuation.

In order to increase the driving foot amplitude without reducing the output force, we introduce the tuning fork principle and propose a new type of tuning fork piezoelectric linear motor with large amplitude vibrator.

There have been some reports on motor with double-driving feet similar to tuning fork[1,2]. However, no follow-up studies were found. The author of this article has developed a double-feet H-shaped linear ultrasonic motor with outer dimensions of 20*12*16 mm and a maximum thrust of 7N[3,4].

2. Configuration

Quartz tuning fork can have four vibration modes (**Fig. 2**) [5]. The tuning fork type double-feet piezoelectric linear motor has two possibilities of bimodal combination, the 'B' mode + the 'A' mode and the pitch mode + the walk mode. Both combinations can produce opposite rotational elliptical motions at the ends of the feet. Just clip the slide rail between the feet to drive it.

In this paper, we adopt the second form, i. e. the bi-modal combination of humanoid gait. With the help of the finite element method, the design steps are as follows: preliminary design of a tuning

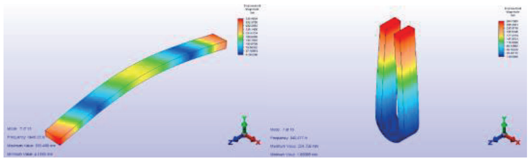


Fig. 1 The first-order vibration modes of free-free beam and U-Shape structure.

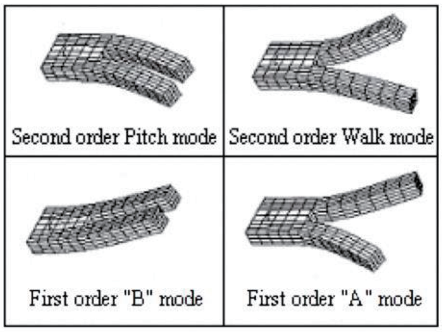
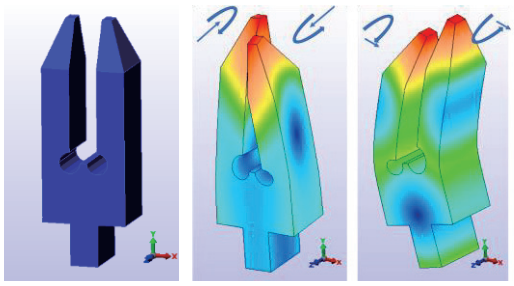
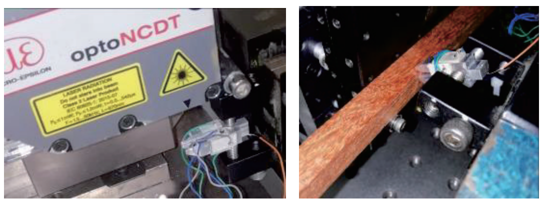


Fig. 2 Vibration modes of quartz tuning fork



(a) (b)

Fig. 3 (a) Original vibrator. (b) Schematic illustration of fundamental operation principle of the two vibration modes of quartz tuning fork



(a) (b)

Fig. 4 (a) Photograph of the prototype piezoelectric linear motor and setup for the displacement measurement. (b) the performance test devices

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fork structure, modification of the structure to make it high fundamental frequency, modification of the structure to make the required two modes adjacent to each other, and modify the geometric parameters to make their resonance frequencies consistent. **Figure 3** shows the prototype of the motor and two coupled modes of the motor calculated by finite element method. They have very close frequencies. find the most sensitive dimension parameters of the two modes.

The outer contour size of the motor is 30*9*6 mm. The cross-sectional dimensions of the two cantilever legs of the motor are 3*6 mm and the length is 15 mm. The tail length of the motor and the radius of the arc groove at the root of the cantilever leg are sensitive to the two modes respectively, which can be used to adjust the frequency consistency.

3. Experimental Results

The resonance response amplitude of the driving foot tips of the tuning fork type vibrator were measured. The test arrangement is shown in **Fig. 4(a)**. The test instrument is optoNCDT laser displacement sensor (ILD1302-200, Micro-Epsilon Measurement Co., Ltd.). For comparison, a cantilever beam with a size of 4*4*32 mm was also tested. The test results are shown in **Table I**. It can be seen that the amplitude of the tuning fork vibrator reaches the same order of magnitude as that of the cantilever beam.

Table I Displacement measurement results

Test object	Frequency (kHz)	Voltage (Vp-p)	Amplitude (μm)	Voltage (Vp-p)	Amplitude (μm)
Cantilever beam	2.99	20	10.5	40	21
pitch mode	15.8	50	7	100	12
walk mode	15.2	40	5.8	80	12.5

The prototype is tested by Polytec laser Doppler scanning vibrometer(PSV-400, Polytec GmbH). The results show that the expected vibration modes of FEM are achieved, and the two-mode frequencies are 15.2 kHz and 15.8 kHz, respectively.

The output performance of the prototype is tested preliminarily. The test device is shown in **Fig. 4(b)**. The results show that the performance of the motor is good, and the forward and backward moving direction can be switched swiftly by changing the phase difference (+/-90 degrees). because the amplitude is very large, the hardwood guide is used to replace the steel guide in the test. Because it is driven by the side of bending mode of the feet, it has large displacement, fast speed and fast response time. But the output thrust is not as large as that of the motor using longitudinal-bending composite mode.

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