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Miniaturization of a U-shape linear piezoelectric motor with double feet

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ABSTRACT

A U-shape linear piezoelectric motor with double driving feet is proposed and tested. It adopts bonded-type structure to realize the miniaturization. Six pieces of PZT ceramic plates are bonded on a U-shape duralumin alloy base to form the motor. This structure makes it has simple fabrication and assemblage processes. The proposed motor produces elliptical movements on the two driving feet by the superimposing of longitudinal vibrations. The resonance frequencies of the two vibration modes are tuned to be close at about 54 kHz. Transient analysis is developed to illustrate the movements of the driving feet. The vibration characteristics of a prototype are measured by a scanning laser Doppler vibrometer. The no-load speed and the maximum output thrust force of the prototype are tested to be 765 mm/s and 7.3 N, respectively. The weight of the miniaturized U-shape piezoelectric motor is about 0.026 kg; its power density is about 6.4 times that of the previous one with bolt-clamped structure.

1. Introduction

In fields such as high precision machine, micro robot, and space mechanism, self-locking and lack of electromagnetic noise are two basic requirements. For electromagnetic motors, the self-locking is usually realized by some special mechanism, which may causes energy consuming and system complexity; the electromagnetic noise is usually avoided by insulation blocking, which increases the system weight and makes the structure complex. The piezoelectric motors are the most suitable ones for the driving of these system as they exhibit characteristics of lack of electromagnetic noise and self-locking when power off [1–4]. Piezoelectric motors work via inverse piezoelectric effect of the piezoelectric element; there is no magnet or coil. Furthermore, they drive the runners by frictional forces, which can result in self-locking when power off; and there is no energy consuming.

In recent years, piezoelectric motors using longitudinal vibrations have been reported. They often exhibit good mechanical output performances as intensive vibrations can be produced on the driving tips. For example, several ring type traveling wave motors using longitudinal vibration transducers were studied [5–8]; there were also few reports about describing longitudinal vibrations hybrid piezoelectric motors with driving feet [9–14]. In a previous work, a U-shape linear piezoelectric motor with bolt-clamped structure was proposed [15]. Three sandwich transducers were set in U-shape; and their longitudinal vibrations were superimposed to generate elliptical movements at the two feet. As the elliptical movements of two feet had the same rotary direction, they could drive a runner linearly together. Typical output of the prototype is no-load speed of 854 mm/s and maximum thrust force of 40 N.

Considering piezoelectric motor with small size is more appreciated in system of precision machine, micro robot, and space mechanism, this study focuses on the miniaturization of the previous U-shape piezoelectric motor. Six pieces of PZT ceramic plates are bonded on a U-shape metal base to form the new motor. Its two resonance frequencies are tuned to be close under suitable structural parameters. The elliptical movements of the two driving feet are investigated to verify the feasibility of this new design. Vibration characteristics and mechanical output performance of a prototype are measured. Comparison between the miniaturized U-shape linear piezoelectric motor and the previous one is given and discussed.

2. Structure of the piezoelectric motor

To realize the miniaturization, the improved piezoelectric motor adopts bonded-type structure to replace the bolt-clamped structure of the previous one. It can be seen as a combination of a U-shape metal base and six pieces of PZT ceramic plates, as shown in

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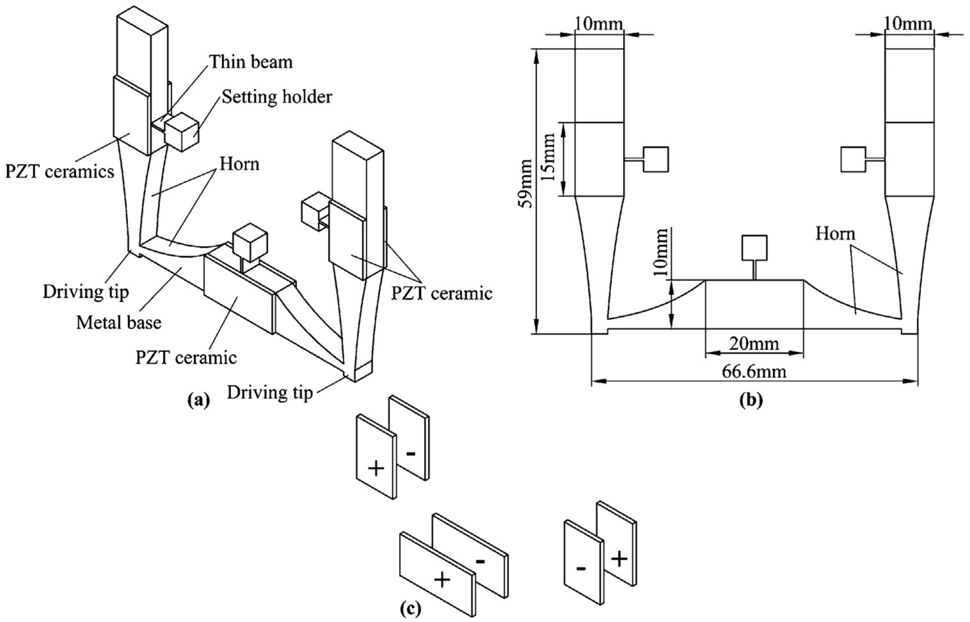

Fig. 1. Structure of the miniaturized U-shape linear piezoelectric motor: (a) three-dimensional model, (b) main structure dimensions, and (c) polarizations of the PZT ceramic plates.

Fig. 1. The metal base consists of one horizontal beam, two vertical beams, three thin beams, and three setting holders; it is fabricated form a duralumin alloy block with thickness of 5 mm by using linear cutting machine. The intersection parts of the horizontal and vertical beams serve as the driving feet. The thin beams and setting holders on the side surfaces of the beams are designed for the elastic supporting. On each vertical beam, two pieces of PZT ceramic plates with size of 15 mm × 10 mm × 1 mm are bonded on the upside and downside surfaces, respectively; and two pieces of PZT ceramic plates with size of 20 mm × 10 mm × 1 mm are bonded on the horizontal beam.

In the miniaturized motor, the six pieces of PZT ceramic plates are polarized along their thickness directions, as shown in Fig. 1(c), in which "+" and "−" are used to illustrate their polarizations. It should be noted that the PZT ceramic plates on the two vertical beams have reverse polarizations: the two pieces of PZT ceramic plates are both bonded on the left vertical beam by their negative electrodes, while the other two pieces of PZT ceramic plates are bonded on the right vertical beam by their positive electrodes.

Compared with the previous piezoelectric motor, the improved one has accomplished distinct size decrease: the horizontal length is decreased to be 73.3 mm from 170.8 mm, the vertical height is shortened to be 59 mm from 108.3 mm, and the thickness is reduced to be 5 mm from 35 mm. As a result of size decrease, the weight of the U-shape piezoelectric motor is decreased to be 0.026 kg from 1.42 kg. Furthermore, the improved piezoelectric motor has more simple structure. There are two end caps, two front caps with horns, one bolt, one flange, twelve pieces of PZT ceramic plates, twelve electrodes, and four insulation coverings in the previous motor. They are simplified to be one metal base and six pieces of PZT ceramic plates in the improved one, which can simplify the fabrication and assemblage processes obviously.

As mentioned in the previous study, the two vibration modes of the proposed piezoelectric motor should have close resonance frequencies to ensure intensive generation of elliptical movements on the driving feet. Finite element method (FEM) was used to accomplish the tuning process; and the finite element model of the motor was founded in ANSYS software. Modal analysis was developed to gain the resonance frequencies of the horizontal and vertical modes. During the FEM modal analysis, SOLID227 element was used for the meshing, fixing boundaries were applied on the setting holders, and Block Lanczos method was adopted to extract the vibration shapes and their resonance frequencies. Based on the design parameter sensitivity of the resonance frequencies in the previous study, the resonance frequencies of the horizontal and vertical modes of the miniaturized motor were finally tuned to be 54.021 kHz and 54.033 kHz, respectively, as shown in Fig. 2.

3. Operating principle and elliptical movements on the driving feet

The vibration shapes shown in Fig. 2 clearly indicate that horizontal and vertical displacements are produced on the two driving feet under the two vibration modes, respectively. Under this condition, elliptical movements can be generated on the two feet if the horizontal and vertical modes vibrate under the same frequency and with a phase difference of 90° in time. To accomplish this purpose, sine exciting voltage is applied on the PZT ceramic plates on the vertical beams, cosine voltage is applied on the PZT ceramic plates on the horizontal beam, and the metal base is linked with the ground electrode. The frequency of the exciting voltage is set close to the resonance frequencies of the two vibration modes. The horizontal and vertical vibration modes are excited with a temporal difference of 90°, which will produce vertical and horizontal displacements at the driving feet; finally, elliptical movements can be formed. The horizontal displacements will push a runner into linear motion, while the vertical displacements will overcome the preload. In one vibration cycle, the vibration shape change of the proposed motor is shown in Fig. 3 (t is time, T is vibration cycle, $n = 1, 2, 3, \ldots$).

Fig. 3 clearly states that clockwise elliptical movements have been produced on the two driving feet when the piezoelectric motor vibrates as (1)–(2)–(3)–(4); the two feet can push the runner move leftward alternately. By exchanging the two exciting voltages, the piezoelectric motor will vibrate as (1)–(4)–(3)–(2); then, counter clockwise elliptical movements will be generated on the two feet, which can push the runner move rightward.

To illustrate the movements of the driving feet, transient analysis was accomplished by applying sine and cosine voltages with effective value of 100 V and frequency of 54.027 kHz on the PZT