An S shape Inchworm Piezoelectric Motor Pre-stressed by an Adaptive Guider

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Abstract:

Piezoelectric motors using inchworm actuation features the advantages of high thrust and high resolution. This paper presents an S shape linear piezoelectric motor (SLPM) based on the principle of inchworm actuation, which has a very compact structure and is pre-stressed by an adaptable guider. After introducing its structure, the operation principle was analyzed. Dynamic performance of S shape stator was analyzed using FE method to find the proper frequency band for operating. A proof-of-concept prototype was manufactured. Experimental results of this prototype verified the design. The prototype has a stable performance that the displacement of one step is 0.625μm while the exciting voltage is 100 V.

Key words: Inchworm, Piezoelectric motor, Adaptive guider, S shape.

Introduction

Piezoelectric motors with operation principle of inchworm actuation have merits such as high thrust, high resolution and linear relationships between performance output and exciting voltage or frequency. According to the initial state of clamping, inchworm piezoelectric motor is classified into two groups, initial clamped type and initial released type. The first group relates to inchworm motors whose clamping mechanisms lock their mover while motor is on the power off while the clamping mechanisms of inchworm motors in the later group released the mover on the power off [1-5].

Because the clamping mechanisms of the initial clamped type inchworm motor are pre-stressed before actuation, they do not need additional locking mechanism to keep its position when the power is off. Besides, by adopting mechanical amplifier to increase the output displacements of piezoelectric units, motors of this type is more stable [4, 5]. However, since the displacement of clamping mechanism is of the order of micrometer, the precision requirements for fabricating and assembling of two clamping mechanism is very high to realize equally pre-stressed. In fact, this is very hard to achieve, which leads to unstable of operation.

Two improvements have been made in the new design presented in this work. Firstly, two clamping mechanisms are placed closely by using a stack structure of S shape, which is more compact and is easy to manufacture. Secondly, the S shape stator is clamped initially by a preload mechanism, which is called adaptive guider. The output of stacked piezoelectric ceramics is amplified by a frame structure and the contact areas for clamping are at the same point along the travel route of mover, so it is easy to achieve alternative clamping of two clamping mechanisms. A proof-of-concept prototype was fabricated and operation testing was conducted.

Construction of SLPM

The S shape linear piezoelectric motor (abbr. SLPM) proposed in this work is comprised of an S shape stator, preload mechanism mover and base, as shown in Fig. 1. The adaptive guider is a linear beam pushed onto stator by pre-stress spring and the beam is supported by a flexible guider.

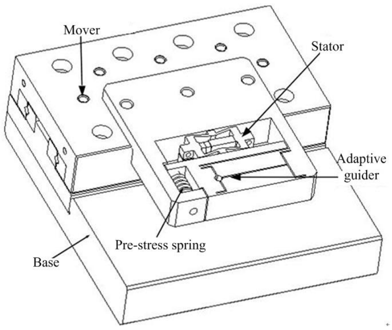

Fig. 1: Construction of SLPM

The S shape stator includes three layers of frame structures, as shown in Fig. 2. The frame in the middle layer is linked by the other two frames in both ends. In the frame of middle layer, there are two stacked piezoelectric ceramics and a support lies between these two elements. The support is fixed to the base through a thin plate.

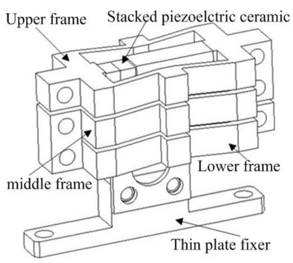

Fig. 2: Construction of S shape stator

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Principle of Operation

To clearly understand the operating principle, simplification of structure was made as shown in Fig. 3; one operating cycle T was divided into six periods and every period show the state of stator.

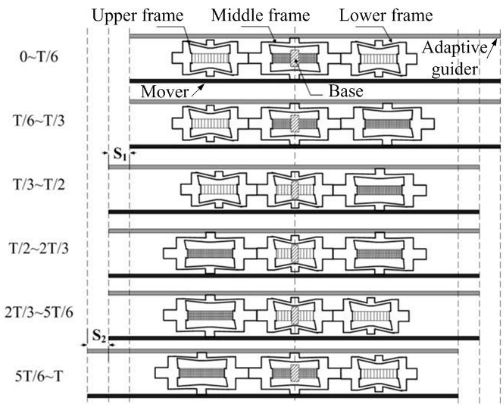

Fig. 3: Actuating sequence of piezoelectric elements

Accordingly, Fig. 4 shows the exciting signals of piezoelectric elements, where U_U represents the exciting signal of stacked piezoelectric ceramic in upper frame, U_M that in middle frame and U_L that in lower frame.

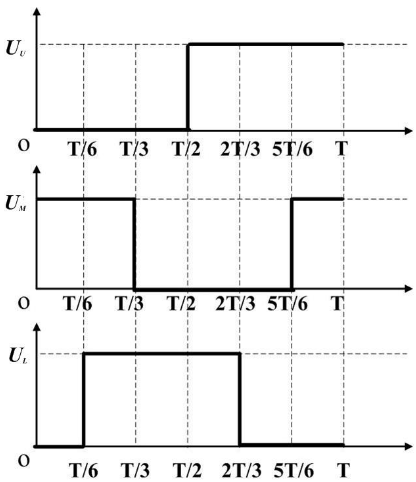

Fig. 4: Exciting signals of piezoelectric elements

During period 0-T/6, two piezoelectric elements in the middle frame elongate and push the middle frame to expand. The adaptive guider is pushed away from the other two frames by the middle frame. In this period, the middle frame locks the mover.

During T/6-T/3, the lower frame expands and locks the mover; during T/3-T/2, the middle frame contracts and the mover steps forward to the left with pace length S_1; during T/2-T2/3, both upper and lower frame clamp the mover; during 2T/3-5T/6, lower frame releases the mover; during 5T/6-T, the middle frame expands again and the mover steps forward to the left with pace length S_2.

In the whole cycle, the mover is pushed to move two times. The clamping force is not generated by deformation of piezoelectric elements but pre-stress, as a result, this design can operate more smoothly. Since three frames are stacked together, it is easy for manufacturing.

Dynamic analysis of Amplifier in Stator

The motor proposed here used three frame structures, the dynamic properties of which determine the operating frequency band. Since the motor work in non-resonance state, the operating frequency should be lower than resonance frequency. To find the frequency limit, a finite element model was built, as shown in fig. 5.

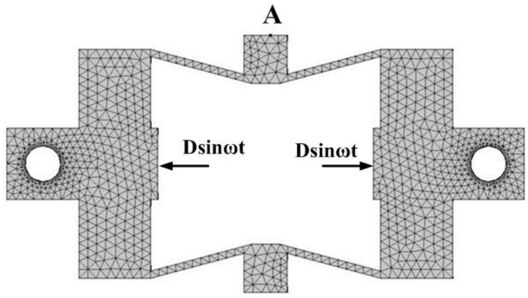

Fig. 5: Finite element model of frame structure

Harmonic analysis of the frame was conducted by applying displacement boundary shown in Fig. 5, where D=2μm. The harmonic displacement response of point A is shown in Fig. 6, where the resonance frequency is about 8.4 kHz.

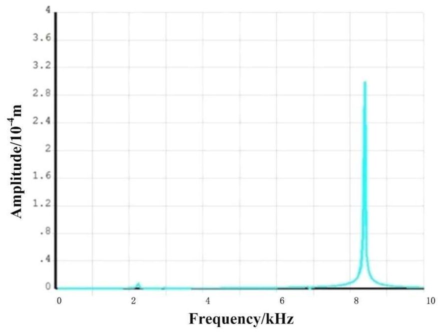

Fig. 6: Harmonic response of frame

Testing of Prototype

A proof-of-concept prototype was fabricated, as shown in Fig. 7.

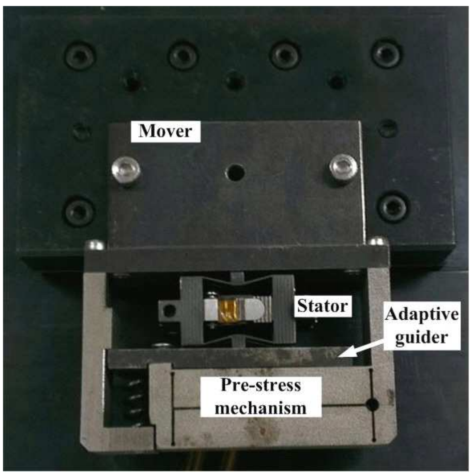

Fig. 7: Prototype of proposed inchworm motor

As analyzed in principle, the motor walks two pace in one cycle. A verification test measuring displacement of mover in one cycle by laser displacement meter with the exciting frequency 1Hz was conducted. Fig. 8 shows the result, which shows the consistence with analysis above. There is an overshoot in the beginning of second pace, which is result from elastic of stator.

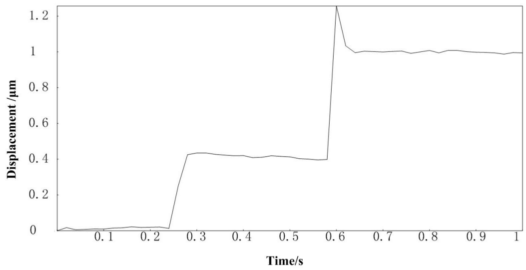

Fig. 8: Walking measurement in one cycle

With driving voltage of piezoelectric elements unchanged, walk testing was conducted under different exciting frequency. Fig. 9 and Fig. 10 show the relationship of displacement versus time and speed versus frequency.

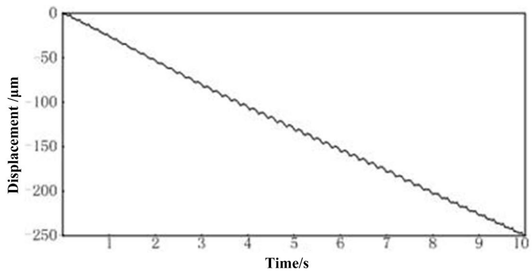

Fig. 9: Walk testing of inchworm motor under 20Hz

It is concluded that the speed increases approximately linear with the driving frequency. The higher the exciting frequency grows, the faster the speed increases. The reason is that when exciting frequency is so high that there is slide between frame and mover and a higher pre-stress is needed to avoid this.

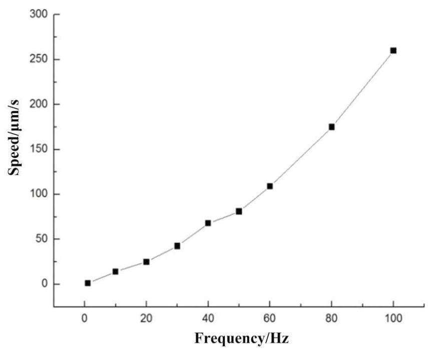

Fig.10: Relationship between exciting frequency and speed

Conclusions

A new design of inchworm with compact structure and amplifying structure was proposed. Two improvements of closely arrangement of clamping mechanism and pre-stress mechanism were made to improve the stability of inchworm motor. Dynamic analysis of frame structure was conducted to find the operation frequency limit of motor. A prototype was made to verify the principle and testing results validate the analysis.

Acknowledgements

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