A low voltage drive linear ultrasonic motor with a semi-oval shaped stator is proposed in this paper. In the stator, two multilayer piezoelectric actuators are clamped in the holder of the stator by pre-stressing to excite a semi-oval ring. The semi-oval shaped stator is designed to have normal vibration and tangential vibration modes, thus these two orthogonal mechanical vibration modes of the stator can be excited to generate elliptical motion at the contact point of the stator.

In design of the motor, ANSYS finite element analysis software was used in this study to accomplish the design and analysis. A prototype motor was fabricated and measured. For single phase signal driving, typical output of the prototype is a no-load speed of 88 mm/s and maximum thrust force of 1.96 N at a voltage of 16 Vp. For two sine wave signals driving, typical output of the prototype is a no-load speed of 106 mm/s and maximum thrust force of 3.33 N at a voltage of 16 Vp.

Keywords: piezoelectric actuator, ultrasonic motor, dynamic analysis, semi-oval

1. Introduction

Piezoelectric materials can be used to make various transducers for energy conversion. Among these transducers, piezoelectric ultrasonic motors using the inverse piezoelectric effect are resonant devices operating at a particular frequency and the corresponding mode. Various types of ultrasonic motors have been investigated in recent decades. Compared with the conventional electromagnetic motors, ultrasonic motors offer many advantages, such as high torque at low speed, light weight, simple structure and no electromagnetic field induction. These advantages have helped ultrasonic motors to be used in some applications that electromagnetic motors cannot satisfy the demands. Various kinds of the ultrasonic motors have been proposed, which are mainly classified into two categories: the traveling wave type and standing wave type. The traveling wave type of ultrasonic motors is designed to generate the traveling wave on the contact surface by the combination of the same mode with a phase difference at one driving frequency. The standing wave type of ultrasonic motors is designed to generate the elliptical motion at the contact point of the stator by the combination of two orthogonal modes.

For the traveling wave type, a ring-type rotating ultrasonic motor invented by Sashida, in which the traveling wave on a ring was obtained by the combination of the same vibration mode motions with a phase difference [1]. Also, a linear ultrasonic motor with a cylindrical stator and slider structure is proposed by Sun, in which the driving mechanism is based on the traveling wave generated on the stator [2]. For the standing wave type, the authors studied a linear ultrasonic motor using an elliptical shaped stator where the normal and tangential modes of the stator are combined to achieve an elliptical motion [3]. To improve the performance of the existing linear elliptical ultrasonic motors, such as the high thrust force by driving a low voltage, an innovative design of the semi-oval shaped linear ultrasonic motor has been further developed and described in this paper.

A low voltage drive linear ultrasonic motor is proposed, which is designed to be driven by a single phase signal or two sine wave signals. This motor is mainly composed of the semi-oval shaped stator, the slider, the preload mechanism and the base. In the stator, a semi-oval ring is excited by two multilayer piezoelectric actuators. In addition, the piezoelectric actuators are clamped in the holder of the stator by pre-stressing. On the other hand, the semi-oval shaped stator is designed to have normal vibration and tangential vibration modes. These two orthogonal mechanical vibration modes of the stator can be excited to generate elliptical motion at the contact point of the stator. By pressing the stator against a slider, the slider can be driven by the stator.

In design process, the structure of the semi-oval shaped stator was simulated by ANSYS finite element analysis software in order to determine the dimensions and the operating frequency offering an elliptical motion for the motor. Based on the simulated results, a prototype ultrasonic motor has been fabricated and its characteristics such as velocity and thrust force have been measured. Also, some design considerations for a semi-oval shaped linear ultrasonic motor are introduced and discussed.
2. Structure and Operating Principle

2.1. Structure

Figure 1 shows the configuration of the ultrasonic motor, which consists of the semi-oval shaped stator, the slider, the pre-load mechanism, the guide and the base. As shown in Fig. 2, the stator using two multilayer piezoelectric actuators perpendicular to one another and clamped by the holder so that the flexible semi-oval shaped part of the stator is driven in a circular or elliptical movement allowing frictional driving of the slider. The piezoelectric actuators are clamped in the holder of stator by prestressing, and the use of multilayer piezoelectric actuators makes it possible to obtain a relatively high vibrational force. There are two additional masses on both sides of the stator can be used to adjust the resonance frequencies of the stator. The greater the added masses, the resonance frequencies are smaller.

The slider is coupled to the stator by the pre-load mechanism, so the stator and the slider are keeping in touch due to a normal force generated from the pre-load spring. The slider is pushed a small step due to the frictional force generated from the elliptical movement of the stator at the contact point, and the process is periodically repeated to produce multiple steps by ultrasonic frequency that is above 20 kHz. The slider is restricted to motion in one direction because of the guider in the slider.

The ultrasonic motor is a friction drive mechanism where friction drive is used to transmit torque and motion from the stator to the slider. Though friction drive produces smooth motion for the small displacement devices, there are some technical challenges associated with the use of this system. The thrust force of the motor depends upon the frictional force generated at the contact interface between the stator and the slider. Usually, it is desirable to have a high frictional force in the friction drive for high output thrust force. However, the performance characteristics of the motor, such as the power transmission efficiency and the thrust force, are depended on the pre-load force, the material friction coefficient and the material wear in the friction drives. Proper selection of the frictional materials used in the friction drive system not only helps minimizing wear but also raising the output thrust force and improving the running efficiency of the system. Therefore, the friction material made from alumina ceramic is bonded on the contact point of the stator and the contacting surface of the slider is also bonded by the alumina ceramic.

2.2. Operating Principle

To drive the slider, two sine voltage signals with phase difference are necessary to apply to the two piezoelectric actuators of the stator for generating an elliptical trajectory at the contact point. Thus, two orthogonal vibration modes of the semi-oval shaped stator are chosen to produce the elliptical trajectory. Then, the contact point of the stator has a vertical displacement component due to the perpendicular vibration mode motion and a horizontal one resulting from the tangential vibration mode motion.

The operating sequence of the stator for a driving cycle is shown in Figs. 3(a)–(f), which is realized when the two vibration modes are excited concurrently with the phase difference of 90 degree in order to have the elliptical tra-