Sensors and Actuators A 165 (2011) 410–414

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

A linear ultrasonic motor using $(K_{0.5}Na_{0.5})NbO_3$ based lead-free piezoelectric ceramics

Jiamei Jin[a], Dandan Wan[b], Ying Yang[a,*], Qian Li[b], Meng Zha[b]

[a] Precision Driving Laboratory, Nanjing University of Aeronautics and Astronautics, 29 Yudao Street, Nanjing 210016, China

[b] College of Materials Science and Technology, Precision Driving Laboratory, Nanjing University of Aeronautics and Astronautics, 29 Yudao Street, Nanjing 210016, China

ARTICLE INFO

Article history:
Received 17 February 2009
Received in revised form 29 October 2010
Accepted 30 October 2010
Available online 9 November 2010

Keywords:
Lead-free
Piezoelectric ceramics
Ultrasonic motor
Quadrate plate

ABSTRACT

A linear ultrasonic motor using lead-free piezoelectric ceramics equipped with quadrate plate transducers has been developed. Four lead free piezoelectric plates driving elements formed a multi-driving-end, producing a large thrust and output velocity. The design of the stator enables two operating modes with coincident frequency. A microscopic view suggests that the material particles at the top of four projections move in ellipses and drive the slider alternately via frictional forces to realize linear motion. The fabrication and characterization of the lead-free piezoelectric ceramics achieving the drive of stator were given in the context.

1. Introduction

Nowadays, linear ultrasonic motors (USMs) have drawn extensive attention due to their merits such as high force density, simple mechanical structure, low speed without additional gear or spindle mechanisms, noiseless operation, high holding forces without an energy supply, absence of magnetic fields, high dynamics and very good positioning accuracy [1,2]. In the normal case, flexural and longitudinal modes are combined to achieve an elliptic micromotion of the material particles on the surface. This micro-motion is converted to direct linear or rotation motion of slider. The ultrasonic motors in the former case are called linear ultrasonic motors. Various kinds of linear ultrasonic motors previously reported [3–8] were based on two different vibration modes. To obtain high amplitudes of the micro-motion and thus achieve high power density, the ultrasonic stator should be driven near its own eigen-frequency. Moreover, a slight frequency deviation would lead to undesirable disturbance of the elliptic motion. It is necessary to design the geometric construction of stator to make the eigen-frequencies of two different modes well-matched. On the other hand, the stators intermittently drive the rotors (or sliders) when the stators contact with the rotors, and the rotors (or sliders) will move further with inertia after the stators separate from the rotors. The duty cycle of the contact and the "flight" determines the output force and the velocity of motor. It is demonstrated that multi-stator or multi-driving-end of single-stator ultrasonic motor could provide large thrust and output velocity [9].

At present, most of the drive elements of USM are $Pb(Zr,Ti)O_3$ (PZT) based ceramics. However, most used PZT ceramics contain about 60 wt.% or more lead, which is a typical heavy element with high toxicity. It is an urgent need for environmental protection to develop lead-free piezoelectric ceramics [10,11]. $(K_{0.5}Na_{0.5})NbO_3$ (KNN), particularly Li-, Sb-, and Ta-modified ones, has been considered a potential candidate for lead-free piezoelectric actuators because of their high piezoelectric properties [12,13].

In this paper, we designed and fabricated a novel linear USM, the stator of which employed a quadrate configuration. In quadrate sheet, for the existence of two vertical centre principal axes of inertia, coincident eigen-frequencies of two same shape modes in two orthogonal directions were obtained, which can effectively avoid frequency deviation. Additionally, the stator consisting of four piezoelectric plates formed a multi-driving-end, enhancing the thrust and output velocity. To explore the application possibility of lead-free piezoelectric ceramics, we manufactured an USM using self-synthesized $(K_{0.44}Na_{0.52}Li_{0.04})(Nb_{0.91}Sb_{0.04}Ta_{0.05})O_3 + x$ mol% MnO_2 ceramics. The electrical properties as well as driving performance of the lead free piezoceramics were demonstrated.

2. USM design and fabrication

The configuration of the stator is illustrated in Fig. 1a. The quadrate stator contains four piezoelectric plates and four projections, and their positions are determined by modal analysis, as shown in Fig. 1b. Here, B_{30} and B_{03} represent modes in x and y direc-

* Corresponding author. Tel.: +86 25 84891937.
E-mail address: yingyang@nuaa.edu.cn (Y. Yang).

0924-4247/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.sna.2010.10.017

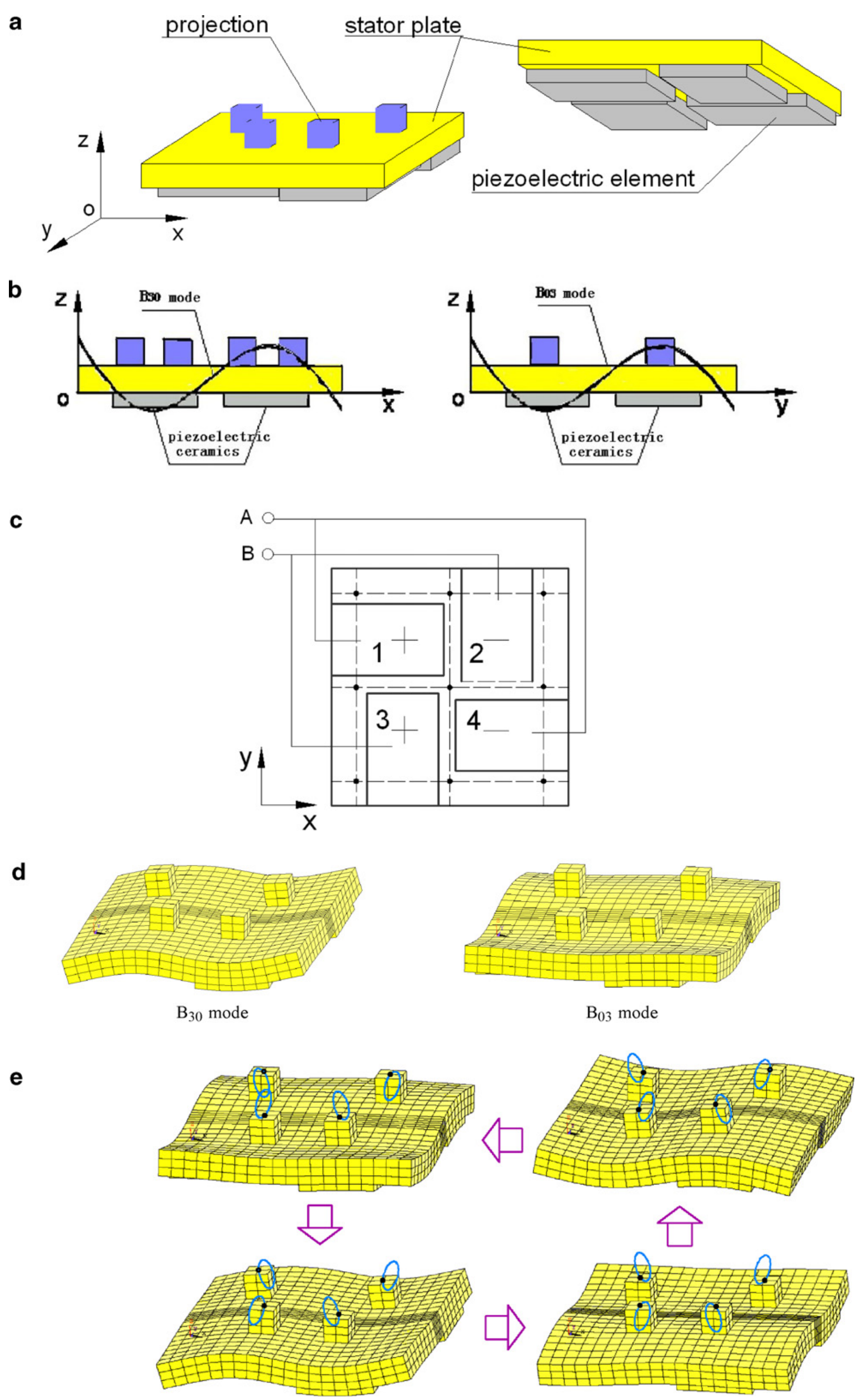

Fig. 1. (a) Structure of the square stator. (b) Operating modal of the square stator. (c) Distribution of the piezoelectric ceramics. (d) Vibration mode analysis of the stator. (e) Harmonic analysis of the stator.

tions, respectively. Moreover, the subscripts indicate that there are three nodal lines in both *x* and *y* directions. In order to obtain a linear motion of slider in the *x*-direction, the projections should only move in *x*–*z* plane. In B_{03} mode, the four projections should only vibrate in the *z*-direction, so two of them were located at the crest and the other two at the trough. In case of B_{30} mode, the four projections should contain motion component in both *x* and *z* directions, and thus they were fixed at the middle point between the crest (or trough) and nodal line to gain equal motion component in different directions. Furthermore, the distribution of piezoelectric ceramic plates is shown in Fig. 1c. The No. 1 and 4 ceramics located at the crest and trough of B_{03} vibration shape, which will