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A novel modal-independent ultrasonic motor with dual stator

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ABSTRACT

In this paper, a novel modal-independent ultrasonic motor with dual stator is proposed, in order to relieve the difficulty of adjustment for coincidence of modal frequencies of a stator for multi-modal coupling type ultrasonic motor (USM). It consists of two stators (an upper stator and a lower stator) and a rotor. The stators are excited the 3rd longitudinal vibration mode, by arranging the location of rotor and two stators, the rotor can realize rotary motion by friction effect with the stators. The rotor is mounted between the maximum deformation location of the upper stator and the nodal line of the lower stator. Since two stators are the same and are excited the same vibration mode, the modal-independent USM can adjust the coincidence of modal frequencies conveniently. Furthermore, the stator of the modal-independent USM has the characteristics of simple structure, which promised advantages of easy designing, manufacturing, miniaturizing and suitable for the mass production of USM. Modal test shows the disparity between the modal frequencies of the stators is 0.78%. Mechanical characteristic test shows the rotary speed of the USM is 75 revolutions per minute (clockwise) and 65.8 revolutions per minute (anti-clockwise) at the voltage of 400 Vp-p. And at the same voltage, the maximum torque is 8.4 N·mm. The resolution of the modal-independent USM can up to 0.34 mrad at the applied voltage of 400 Vp-p.

1. Introduction

Compared with electromagnetic motors, ultrasonic motor (USM) has advantages of compact structure, high resolution of displacement, and fast response [1–4]. Studies indicated that the use of USM is getting increased in many fields, such as optical instrument, precision positioning system, biomedical science and aerospace [5–8]. However, the mentioned USMs still remain some defects. The majority of which is the difficulty of adjustment for coincidence of modal frequencies of a stator for multi-modal coupling type ultrasonic motor.

Lots of USMs that has only one stator are reported. The orthogonal vibration modes are usually excited on a piezoelectric vibrator to induce the motion [9–12]. Two modes of metal elastic body are calculated via finite element analysis (FEA) to match the modal frequencies that increase the difficulty of the design of USM. Besides, the stator requires high accuracy manufacturing for the demand of frequency consistency [4,13]. Furthermore, taking the abrasion into consideration, frequency consistency will deteriorate during the working process of USM, since frequency sensitivity various from different modes with the change of dimension caused by abrasion [14].

In this study, we propose a modal-independent USM with dual stator based on optimizing the location of a rotor and two stators which excited at the same mode. Rotary motion is generated by the friction between stators and rotor. As two modes excited on stators are the same, the demand of frequency consistency can be satisfied conveniently. Besides, the frequency consistency problem of stator caused by abrasion is eased, because the influences of dimension change on modal frequency of two stators are similar in the modal-independent ultrasonic motor. On the following, we will describe the motor's design, its driving principle and characteristics.

2. Design of the modal-independent ultrasonic motor

The rotary modal-independent ultrasonic motor is shown in Fig. 1. It is composed of two stators, one rotor, four springs, four dowels, two fix plates, two bolts and nuts. The stator consists of a metal elastic body and two pieces of piezoelectric ceramic plate, as shown in Fig. 2. The rotor consists of a deep groove ball bearing, a shaft and a bottom plate, as shown in Fig. 3. The outer ring of the bearing contact with the stators and the inner ring of the bearing assembled with a shaft by interference fit. The shaft is fixed to

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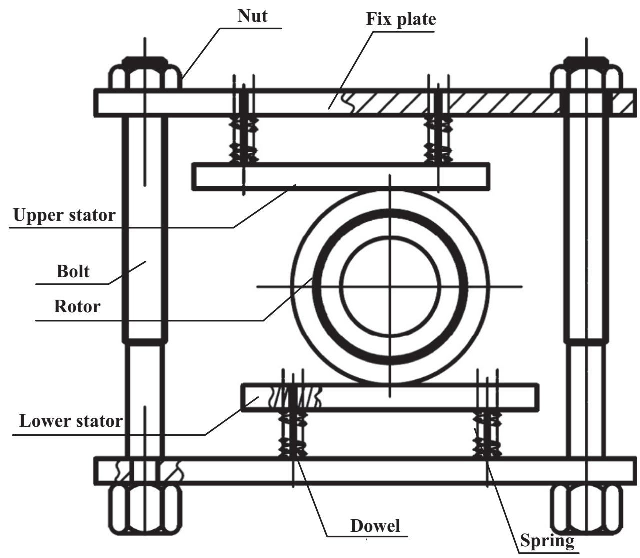

Fig. 1. Structure of modal-independent USM.

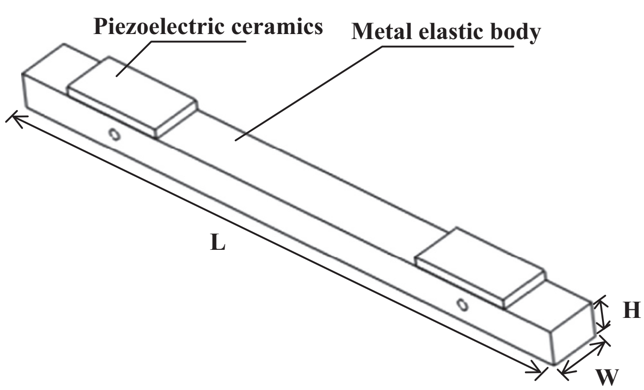

Fig. 2. Structure of stator.

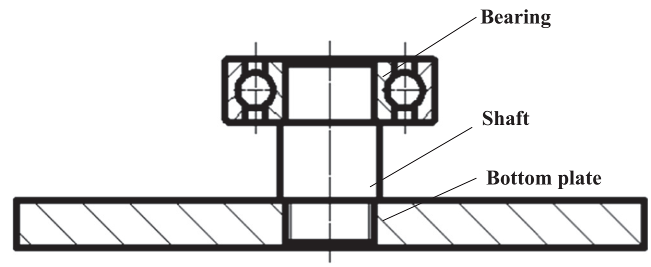

Fig. 3. Structure of rotor.

the bottom plate through a screw thread connection. The 3rd longitudinal vibration mode is selected as the work mode, as shown in Fig. 4. For the upper stator, the location of the first and the third nodal line are used for fixing, and the maximum deformation between the first and the third nodal point is chosen to drive rotor. While for the lower stator, the location of the first and the third nodal line is used for fixing, and the location of the second nodal is used for driving. Two pieces of PZT ceramic plate are glued on the first and the third nodal lines. A hole is designed at the first and the third nodal for fixing. The rotor is settled between two stators. Pins are used to join the fix plants and stator, and clearance fit is used between pins and stators. Interference fit is used between fix plant and pins. Springs are used to adjust the pre-load and compensate the abrasion between rotor and vibrator, and bolt and nut are used for fixing and to adjust the pre-load.

The parameter of the stators is determined via finite element analysis (ANSYS 15.0, ANSYS Inc., Canonsburg, PA). As there is only one mode to excite and the width of PZT ceramic plate is 5mm, the length dimension and the width dimension of the stators are taken to be 60mm and 5mm. The relation between height dimension and frequency of the 3rd longitudinal vibration mode of the stators is shown in Fig. 5. The height dimension of the stator is taken to be 3.5 mm.

The workload of finite element analysis has been reduced greatly, because it is easy to find the 3rd longitudinal vibration mode on the beam. It simplifies the design work of USM and makes

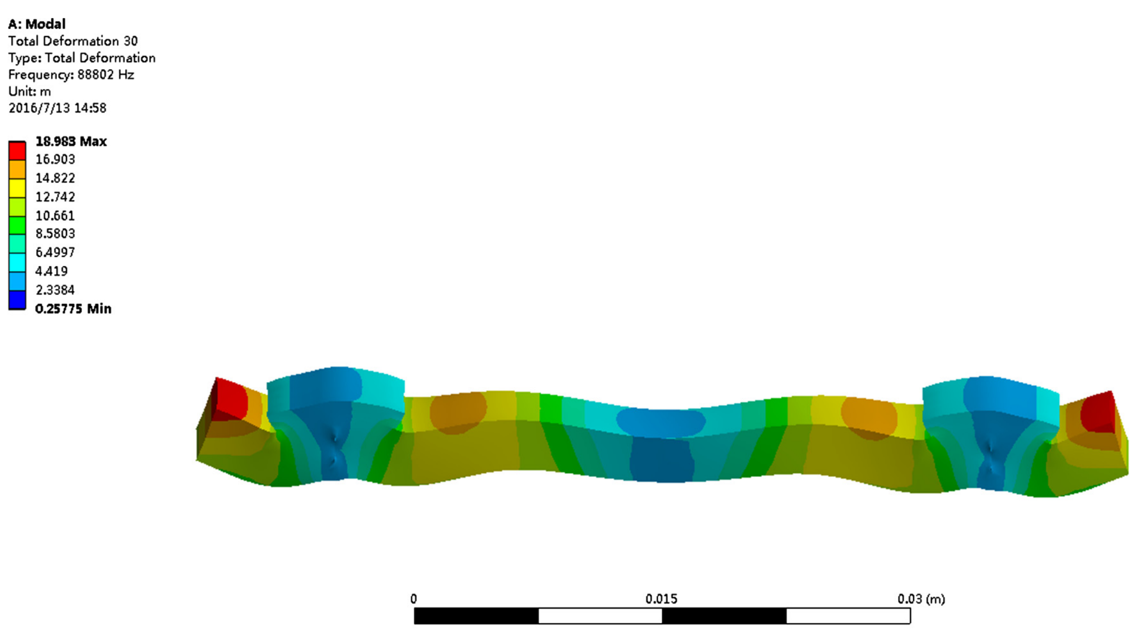

Fig. 4. The 3rd longitudinal vibration mode of stators.