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A novel in-plane mode rotary ultrasonic motor

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Abstract Ultrasonic motors have the merits of high ratio of torque to volume, high positioning precision, intrinsic holding torque, etc., compared to the conventional electromagnetic motors. There have been several potential applications for this type of motor in aerospace exploration, but bearings and bonding mechanism of the piezoelectric ring in the motors limit the performance of them in the space operation conditions. It is known that the Langevin type transducer has excellent energy efficiency and reliability. Hence using the Langevin type transducer in ultrasonic motors may improve the reliability of piezoelectric motors for space applications. In this study, a novel in-plane mode rotary ultrasonic motor is designed, fabricated, and characterized. The proposed motor operates in in-plane vibration mode which is excited by four Langevin-type bending vibrators separately placed around a ring-shaped stator. Two tapered rotors are assembled to the inner ring of the stator and clamped together by a screw nut. In order to make the motor more stable and convenient to fix, a thin cylindrical support is placed under the stator ring. Due to its no-bearing structure and Langevin transducer excitation, the prototype ultrasonic motor may operate well in aeronautic and astronautic environments.

1. Introduction

Requirements for actuators used in aircrafts or robotic arms for space exploration are much more rigorous than for those used in ordinary applications.[1–3] An ultrasonic motor, which is an actuator utilizing ultrasonic vibration to drive, has features such as electromagnetic interference free, low noise, light weight, compact structure, etc.[4,5] Thus, the ultrasonic motor is competitive compared to traditional electromagnetic motors while being applied as a mechanical driving unit in aeronautic and astronautic systems.

In previous research on morphing aircrafts in our lab, Liu et al.[6] designed a variable camber wing driven by ultrasonic motors (see. Fig. 1). It mainly consists of a driving governor, ultrasonic motors, inner support, and trailing edges. Multiple ultrasonic motors are employed to drive the trailing edges for realizing the wing morphing. The proposed mechanism was experimentally confirmed by the classical traveling wave rotary ultrasonic motors. For improving the stability of such a system, using ultrasonic motors with reliable and compact structures should be helpful.

Till now, ultrasonic motors are mainly divided into ultrasonic motors with bonding piezoelectric plates[7] and with Langevin transducers.[8,9] Ultrasonic motors with Langevin

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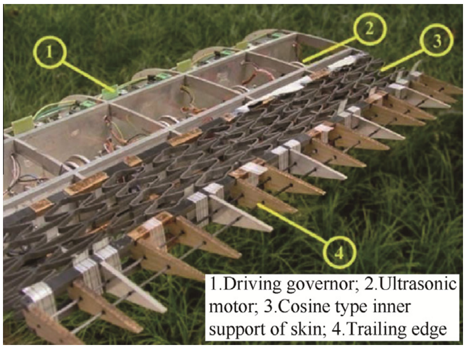

Fig. 1 Inner structure of the variable camber wing.[6]

transducers have good stability and high adaptability because no bonding material is used between piezoelectric and metal parts.[10,11] Jin and Zhao proposed a novel rotary ultrasonic motor using a bar-shaped transducer which has a simple structure; but the normal distribution of the Langevin transducer is not favorable for minimizing, and the clamping structure is not very stable.[12] Iula et al. proposed a high-power traveling wave ultrasonic motor which used a longitude Langevin transducer; but the size of the motor is too big.[13–15] In addition, Liu et al. did a lot of work in designing ultrasonic motors with Langvin transducers, and proposed a cylindrical traveling wave ultrasonic motor which had a compact structure.[16–18]

In this paper, a novel in-plane mode rotary ultrasonic motor is designed, analyzed, fabricated, and measured. Four bending Langevin transducers are distributed around the stator ring for exciting its in-plane flexural vibration. The appearance size is minimized by using the bending vibration mode of the Langevin transducers. A thin cylindrical support is placed under the stator ring which makes the motor's fixing more stable and convenient. Based on the simulation with ANSYS software, the size parameters of the stator and the basic working mode are determined. The merits of this prototype motor are as follows: compact structure, stable fixing, simple piezoelectric structure, same vibration mode, and good stability. Designing and measuring results give useful guidelines for using the ultrasonic motor in aerospace environments.

2. Structure design

2.1. Configuration of the motor

Fig. 2 shows the configuration of the novel in-plane mode rotary ultrasonic motor, which is mainly composed of the stator, rotor *A*, rotor *B*, a nut, and a leaf spring. Rotor *A* has a tapered bottom with a long shaft in the center. Being similar to rotor *A*, rotor *B* is also tapered but with a center hole holding the shaft of rotor *A*. Rotor *A* is pressed on the bottom driving face of the stator with the shaft through it. Rotor *B* is assembled with the shaft of rotor *A* and placed on the top surface of the stator. The leaf-shaped spring is assembled on rotor *B* and pressed by the nut which is screwed to the end of rotor *A*'s shaft. Thus, two tapered rotors are fitted on the two conical driving faces of the stator, and the preload between the rotor and the stator can be adjusted by deformation of the leaf spring.

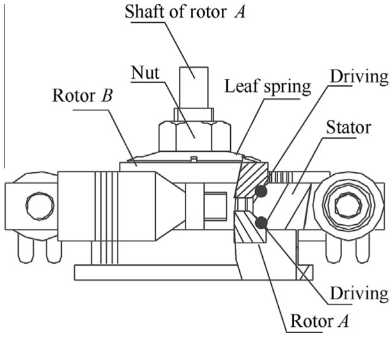

Fig. 2 Configuration of the ultrasonic motor.

Piezoelectric material in the transducers is PZT-8H. It has piezoelectric constant d_{33} of 200×10^{-12} C/N, electromechanical coupling factor k_{33} of 0.60, mechanical quality factor Q_{m} of 800, dielectric dissipation factor $\tan\delta$ of 0.5%, density of 7450 kg/m^3, and Curie temperature T_{c} of 300 °C.[5] Phosphor bronze is chosen for making the stator ring and the transducers' metal parts, and aluminum for making the rotor. Additionally, PTFE composite material is utilized as the friction layer adhered to the tapered faces of the rotors, which can make the performance of the motor more stable and keep the motor noise-free.

2.2. Construction of the stator

As shown in Fig. 3, the stator consists of one stator ring and four bending Langevin transducers (A_2, B_2, A_3, B_3). The stator ring can be divided into a top ring, a thin support, and a bottom base. There are two conical driving faces in the inner side of the top ring and many teeth are cut out for enlarging the vibration amplitude. Four Langevin transducers are assembled on the same side of corresponding projections with the length direction tangential to the top ring. The cylindrical support connects the top ring and the bottom base. The bottom base used for fixing the motor to a target surface has a thick ring-shaped structure which makes the motor's fixing more stable

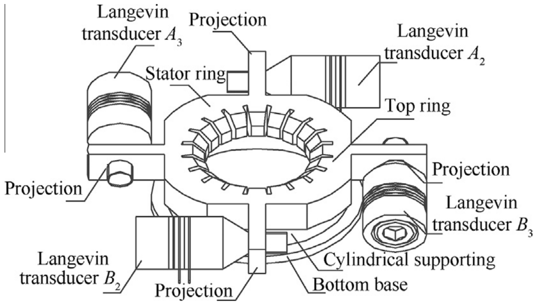

Fig. 3 Construction of the stator.

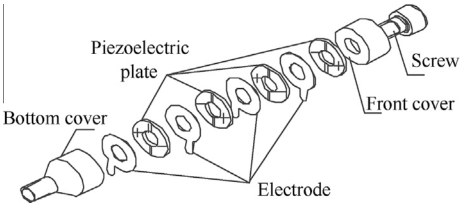

Fig. 4 Details of the Langevin transducer.