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Characteristics of ring type traveling wave ultrasonic motor in vacuum

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The characteristics of ultrasonic motor strongly depend on the properties of stator/rotor contact interface which are affected by ambient environment. With the developed apparatus, load properties of two ring type traveling wave ultrasonic motors in atmosphere, low vacuum and high vacuum were studied, respectively. Wear of friction material, variations of vacuum degree and the temperature of motor during the experiment were also measured. The results show that load properties of motor A in vacuum were poorer than those in atmosphere, when load torque M_f was less than 0.55 N m. Compared to motor A, load properties of motor B were affected a little by environmental pressure. Wear of friction material in vacuum was more severe than wear in atmosphere. The temperature of motor in vacuum rose more quickly than it in atmosphere and had not reached equilibrium in 2 h experiment. However, the temperature of motor in atmosphere had reached equilibrium in about forth minutes. Furthermore, outgas was also observed during experiment under vacuum conditions.

1. Introduction

Ultrasonic motor (USM) is a new type of motor where friction drive is used to transmit torque and motion via the friction force. Due to its special operational principle, USM offers certain advantages against conventional electromechanical actuators like, e.g., high torque (force) at low speed without gear, holding torque (force) without power supply or additional brake, excellent start/stop dynamics and simple mechanical design. Lubricating oil is not required and no magnetic noise is generated. Consequently, an ultrasonic motor is considered to be a promising actuator under a vacuum environment [1].

Considerable experimental researches have been undertaken to investigate the characteristics of USM under vacuum conditions in recent years. Ishii has studied friction materials of an USM driven under a vacuum environment [2]. Morita investigated load characteristics of a Langevin vibrator type USM in atmosphere and vacuum of 10^{-6} Pa and found that these two values of rotational speed and torque under vacuum conditions were slightly smaller than those in atmosphere [3,4]. Niino has tested USM's total life time of operation without replacing friction parts in vacuum of 10^{-8} Pa and found that less adhesive material was preferred for selecting friction material of ultrasonic motor [5]. Zhou has investigated the contact state between stator and rotor of traveling wave USM in atmosphere and vacuum. She thought that the existence of acoustic levitation was the reason why the separating time between stator and rotor in atmosphere was longer than the separating time in vacuum [6]. Su has tested load characteristics of ring type traveling wave USM in atmosphere and vacuum and shown that stalling torque of USM in vacuum is larger than stalling torque in atmosphere. But her experiment was taken only in one vacuum degree [7]. Previously the authors have ever discussed performances of USM under vacuum and high temperature conditions [8,9].

Tribological processes occurring in high-frequency frictional contacts determine not only the torque–speed characteristics of ultrasonic motors, but also their lifetime and long-term behavior. Maeno analyzed the rotor/stator contact of a ring type USM by using finite-element method and found that stick/slip phenomena exists in the stator/rotor contact area when USM is running [10]. Adachi et al., investigated the microscopic force transfer mechanism of intermittent contact type USM and proposed a modified Coulomb friction law, where the coefficient of friction depends on the relative local displacement of contact asperities [11]. Rehbein and Wallaschek tested friction and wear of several kinds of materials which is frequently used in traveling wave piezoelectric ultrasonic motors under high-frequency fretting conditions and thought that local vibrations and the decrease in the real contact area as a consequence of micro-impacts were the reason why the coefficient under high-frequency fretting conditions is much smaller than the conventional coefficient. Then Wallaschek gave a survey of friction contacts in ultrasonic motors in 1998 [12,13]. Storck et al., studied the friction reduction in the presence of ultrasonic vibrations based on the rigid Coulomb friction and confirmed its validity by experiments [14,15]. However, there are few studies

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on friction mechanism of USM in vacuum. So, further experimental research on USM in vacuum is outstandingly important.

In the present paper, two ring type traveling wave ultrasonic motors were studied in atmosphere, low vacuum and high vacuum. Speed–torque characteristics of the two ultrasonic motors were measured and compared. Wear, outgas and temperature of ultrasonic motor during experiment were also measured and discussed. The purpose of this study are exploring performances of USM in vacuum, providing experimental datum and theory guidance for improving the design of USM in vacuum and accelerating its application in space field.

2. Experimental apparatus and procedures

2.1. Experimental apparatus

Fig. 1 is the principle of traveling wave USM. The rotor, which is pressed against the stator with a certain normal force, is driven in the opposite direction to the stator's traveling wave movement by means of the friction force at the stator/rotor contact areas. And contact areas moves with the traveling wave excited in the stator by piezoelectric ceramics bonded on the bottom side of the stator. Based on Kirchoff plate theory, the neutral plane of stator moves in the way of an ideal traveling wave

$$w(r,\phi,t) = R(r)\cos(n\phi - \omega t)$$

with amplitude $R(r)$, the number of nodal lines n and the excitation frequency ω. There are many tribological problems in USM need to study, especially under various environmental conditions.

The two ultrasonic motors used in this experiment are motor A and motor B. They have the same following parameters: the outer diameter of stator is 60 mm, the vibration mode of stator which was calculated by using the FE code ANSYS is B(0,9) (as shown in Fig. 2) and the materials of stator, rotor, rotor shaft and friction layer are brass, duralumin, copper and PTFE based composite, respectively. The friction layer was adhered to the teeth of stator. The difference of the two ultrasonic motors is the used bearings. In motor A, bearings are metal bearings In motor B, bearings are full ceramic ones. The stator of motor A is shown in Fig. 3.

The sketch of the testing rig used in this study is shown in Fig. 4. The test rig was designed to investigate friction and wear behaviors and load properties of ultrasonic motor under vacuum and low temperature conditions. It can supply load to USM and measure rotational speed and torque (force) of USM easily by hysteresis brake, proximity sensor and force sensor, respectively. The hysteresis brake is connected with the shaft of USM by a resilient coupling. The scale of output resistive torque of hysteresis brake is controlled by current. The USM is fixed in a retainer which is positioned by a ball bearing. The retainer of USM will drive an arm to press on the force sensor when USM works. The measured values were shown on-line on USM control panel. The force sensor can be moved horizontally on a slot of the plate to change the distance between the center of motor and the probe of force sensor. The material of plates which are used to fix hysteresis brake and

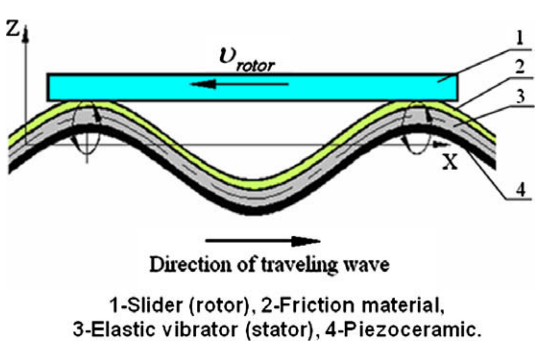

Fig. 1. Principle of traveling wave ultrasonic motor.

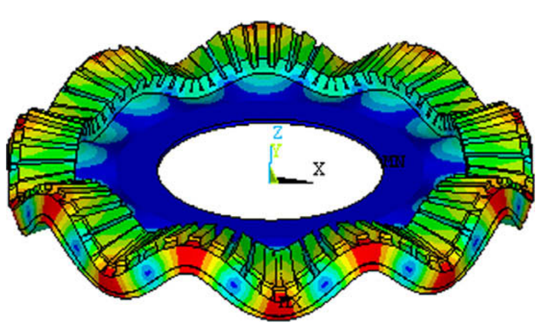

Fig. 2. Vibration mode of stator.

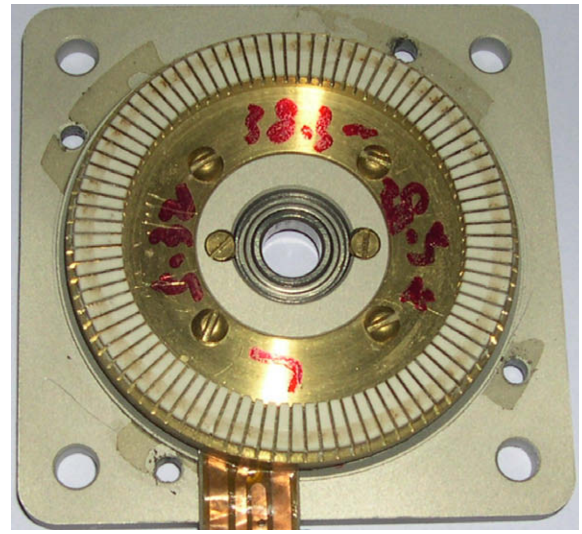

Fig. 3. Photograph of stator of motor A.

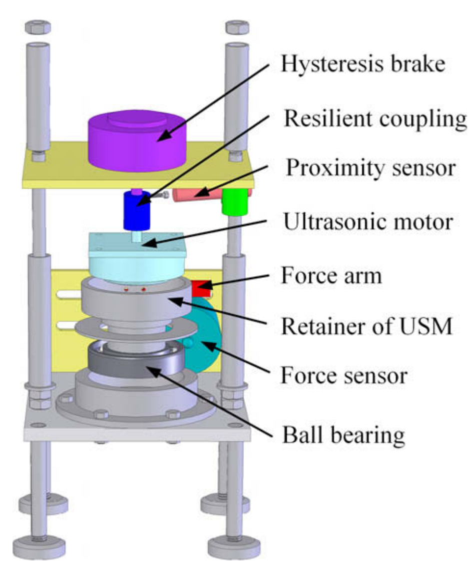

Fig. 4. Sketch of testing rig of USM.