Proposal and Development of Ultrasonic Motion Control Mechanism

Tinghai CHENG*, Han GAO, and Gang BAO
School of Mechatronics Engineering, Harbin Institute of Technology, Harbin, 150080, China
* Corresponding author, E-mail: chengtinghai@163.com

Abstract:

A novel mechanism described as ultrasonic motion control mechanism (UMCM) comprising an ultrasonic actuator and screw shaft was proposed. The orthogonal bending vibration modes of cylindrical ultrasonic actuator are excited to generate a traveling wave propagating along the internal thread surface. The traveling wave mainly produces a movement trend between ultrasonic actuator and screw shaft. Furthermore, on account of the friction reduction effect induced by ultrasonic vibration, the friction coefficient between the ultrasonic actuator and screw shaft is reduced and the screw self-locking status is transformed. The on/off control operations of screw mechanism can be achieved.

Key words: Ultrasonic motion control mechanism, ultrasonic vibration, traveling wave, friction reduction effect, self-locking.

Introduction

The piezoelectric effect of piezoelectric ceramics can realize the conversion from electric energy to mechanical energy, and has been utilized widely in ultrasonic motor (USM) [1]. As an important research branch in ultrasonic motor, cylindrical ultrasonic motor gains its driving friction by exciting the stator in the resonant state with the preload and generates a driving traveling wave on contact surface between stator and rotor by utilizing coupled bending vibration modes [2].

The friction reduction effect with ultrasonic vibrations indicates an obvious friction coefficient reduction phenomenon between two contact surfaces when ultrasonic vibrations are introduced in friction couples [3, 4]. It has been proved by numerous experiment investigations that the friction coefficients between friction surfaces have apparent decrease in different extent, no matter between rigid-rigid (metal/metal) or rigid-soft (rubber/metal) friction couples [5, 6].

In this paper, we proposed a novel mechanism which can realize the status transition between screw pair self-locking and unlocking, on the basis of ultrasonic driving and friction reduction effect by ultrasonic vibrations. And the mechanism is described as ultrasonic motion control mechanism (UMCM). The structure, principle, and main output performance under mass load of UMCM were presented.

Structure and Principle

Figure 1 shows the structure of ultrasonic motion control mechanism proposed. It is composed of ultrasonic actuator and screw output shaft, which are connected by normal screw thread pair. The ultrasonic actuator is primarily consisted of a hollow cylinder metal tube grounded and four PZT plates which are divided into two groups and excited by alternating current signals U_A and U_B, respectively. The PZT plates are polarized in thickness direction with d_{31} effect, and pasted outside the metal tube with epoxy resin adhesive.

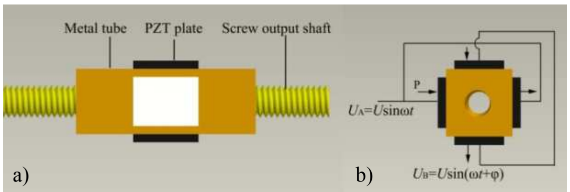

Fig. 1: Illustrations of ultrasonic motion control mechanism. a) Structure of UMCM b) Schematic of PZT plates polarization and excitation

The first bending vibration modes of cylindrical ultrasonic actuator which are orthogonal to each other both in spatially and temporally are excited and a driving traveling wave is generated on the contact surface between actuator and shaft by utilizing coupled vibrations. While this traveling wave in ultrasonic motion control mechanism is to provide a movement tendency between the output shaft and ultrasonic actuator.

Similar to cylindrical ultrasonic motor, the moving directions of traveling wave can be converted by changing the phase difference φ. As an illustration, when the phase difference φ is 90° or 270°, two traveling waves which are in different traveling directions can be generated accordingly [7].

In the mean time, with the friction reduction effect by ultrasonic vibration, the friction coefficient between output shaft and ultrasonic actuator is decreased obviously. When the friction coefficient decreases until the self-locking status of screw mechanism is transformed, the output shaft can output a motion on the condition of external force, when the mechanism can be seen as on operation.

For instance, when there are no ultrasonic vibrations, the friction coefficient of output shaft and ultrasonic actuator is the static friction coefficient which is in normal condition. The self-locking condition of screw pair can be

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satisfied in eq. (1), by selecting proper screw dimension. Thus, ultrasonic motion control mechanism is in the off operation state.

$$S \leq \frac{\pi d_2 \mu}{\cos\beta} \quad (1)$$

Where, S is the thread lead, d_2 is the middle diameter of screw, μ is the static friction coefficient between output shaft and ultrasonic actuator, and β is the flank angle of screw.

When the actuator is excited, the friction coefficient between output shaft and ultrasonic actuator decreases sharply on account of ultrasonic vibrations. When the self-locking status is changed, as is shown in eq. (2), the ultrasonic motion control mechanism is in the unlocking condition.

$$S > \frac{\pi d_2 \mu_s}{\cos\beta} \quad (2)$$

Where, μ_s is the dynamic friction coefficient between output shaft and ultrasonic actuator with ultrasonic vibrations. For metal-metal friction couple, μ_s has a 20% value of μ, approximately [8].

Prototype and Testing Results

Figure 2 is the photograph of UMCM prototype developed in this research. The length, width and inner diameter of ultrasonic actuator are 20 mm, 8 mm, and 4 mm, respectively, with a weight of 24 g. Keep the UMCM in one-way output state, and the downward direction output performance with mass load was tested.

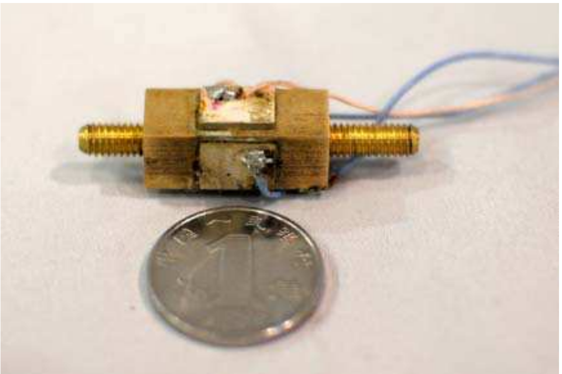

Fig. 2: Photograph of UMCM prototype

Figure 3 illustrates the load characteristics testing results of UMCM with an operating frequency f 49.30 kHz. It can be seen that the UMCM has a different load performance with USM.

It can be revealed that the load characteristics of UMCM can be divided into two characteristic regions according to different mass load F_m from Fig. 3. (1) The output velocity υ of output shaft decreased initially as the mass load F_m increased, when the load characteristics is quite similar to USM. (2) When the mass load exceeds a certain value, the output velocity υ attains a steady value. Thus, the UMCM performs as a mechanical switch. The specific mass load is defined as inflection load and the corresponding velocity is named as steady speed in this paper. The steady velocity increases as the exciting voltage V_{rms} increases, while the inflection load has no direct relationship to exciting voltage V_{rms}.

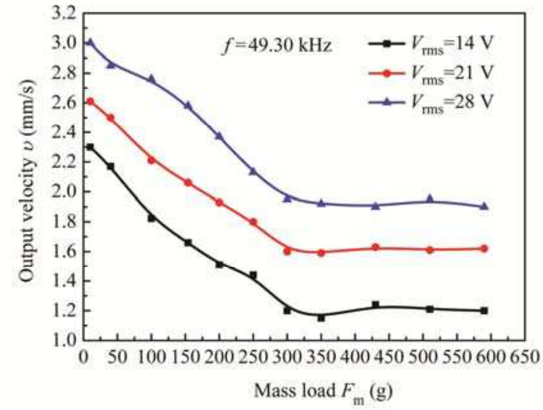

Fig. 3: Load characteristics of UMCM

Summary

A ultrasonic motion control mechanism (UMCM) utilized ultrasonic driving and friction reduction effect by ultrasonic vibrations was presented, and the on/off control operations of traditional screw mechanism can be realized. UMCM has the advantages of simple structure, large bearing capacity, low driving voltage, and may has wide application prospect on precision positioning, protecting mechanism, and velocity control system.

References

[1] K. Uchino, **Piezoelectric Ultrasonic Motors: Overview**, Smart Materials and Structures 7, 273-285 (1998); doi: 10.1088/0964-1726/7/3/002

[2] B. Koc, S. Cagatay, K. Uchino, **A Piezoelectric Motor Using Two Orthogonal Bending Modes of a Hollow Cylinder**, IEEE Transactions on Ultrasonics Ferroelectrics and Frequency Control 49, 495-500 (2002); doi: 10.1109/58.996568

[3] T. Maeno, D. B. Bog, **Effect of the Hydrodynamic Bearing on Rotor/Stator Contact in a Ring-Type Ultrasonic Motor**, IEEE Transactions on Ultrasonics Ferroelectrics and Frequency Control 39, 675-682 (1992); doi: 10.1109/58.165550

[4] H. Storck, W. Littmann, J. Wallaschek J. **The Effect of Friction Reduction in Presence of Ultrasonic Vibrations and Its Relevance to Travelling Wave Ultrasonic Motors**, Ultrasonics 40, 379-383 (2002); doi: 10.1016/S0041-624X(02)00126-9

[5] V. C. Kumar, I.M. Hutchings, **Reduction of the Sliding Friction of Metals by the Application of Longitudinal or Transverse Ultrasonic Vibration**, Tribology International 37, 833-840 (2004); doi: 10.1016/j.triboint.2004.05.003

[6] T. H. Cheng, H. Gao, G. Bao, **Influence of Ultrasonic Vibrations on the Static Friction Characteristics of a Rubber/Aluminum Couple**, Chinese Physics. Letters. 28, 124301-124303 (2011); doi: 10.1088/0256-307X/28/12/124301

[7] L. H. Luo, H. Zhu, C. S. Zhao, et al, **Cylinder-Shaped Ultrasonic Motors 4.8 mm in Diameter Using Electroactive Piezoelectric Materials**, Applied Physics Letters 90, 901-904 (2007); doi: 10.1063/1.2437093

[8] V. L. Popov, J. Starcevic, A. E. Filippov, **Influence of Ultrasonic in-Plane Oscillations on Static and Sliding Friction and Intrinsic Length Scale of Dry Friction Processes**, Tribology Letters 39, 25-30 (2010); doi: 10.1007/s11249-009-9531-6

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