A Compact Inertial Rotary Stick-slip Actuator with Improved Output Velocity and Torque in Bi-direction

Siyang SONG, Shaoqi HUANG, Cheng LI, Shubao SHAO, Liang Li, Chongpu ZHAI*, Minglong XU*

State Key Laboratory for Strength and Vibration of Mechanical Structures, School of Aerospace, Xi'an Jiaotong University, No.28, Xianning West Road, 710049, Xi'an, P.R. China

* Corresponding author, Email: mlxu@xjtu.edu.cn, zhaichongpu@xjtu.edu.cn

Abstract

The output performance of stick-slip piezoelectric actuators is comprehensively determined by the electro-mechanical responses of the driving unit, control strategy, and the contact status between the driving unit and the slider. Most previously developed inertial piezoelectric actuators face the problems of frequency dependence, motion speed, excessive volume, step resolution as well as loading capacity. To exhaustively improve actuation performance while maintaining low power consumption, we propose a compact bi-directional piezoelectric-based rotary actuator incorporating the rhombic amplification mechanism, adjustable preload, and simulation method based on by LuGre friction model for comparison. A prototype is fabricated and examined, which accomplishes the maximum load torques of 27.78 and 30.87 N.mm in clockwise and anticlockwise directions, respectively, at the highest rotational velocity of 0.4720 rad/s, which is almost equal in two directions. Compared with previously reported inertial actuators, the performance of the proposed actuator is significantly enhanced, promising in applications requiring nanometer resolution, long stroke, large holding and driving forces.

1 Introduction

Stick-slip actuators have recently been extensively investigated due to their numerous advantages, including long stroke, high precision, and simple structure [1]. Various methods such as anisotropic friction surfaces and coupling mechanisms [2], have been proposed to improve stick-slip actuator performance, especially in terms of load capacity and velocity. However, these asymmetric factors just improve actuator performance in only one direction. In this work, a rhombic amplification mechanism (RAM) is applied to the stick-slip mechanism to improve actuator performance in bi-direction with compact size. To verify the improvement of the proposed rotary actuator, simulations and experiments were both conducted and utilized in this work.

2 Design and modeling of actuator

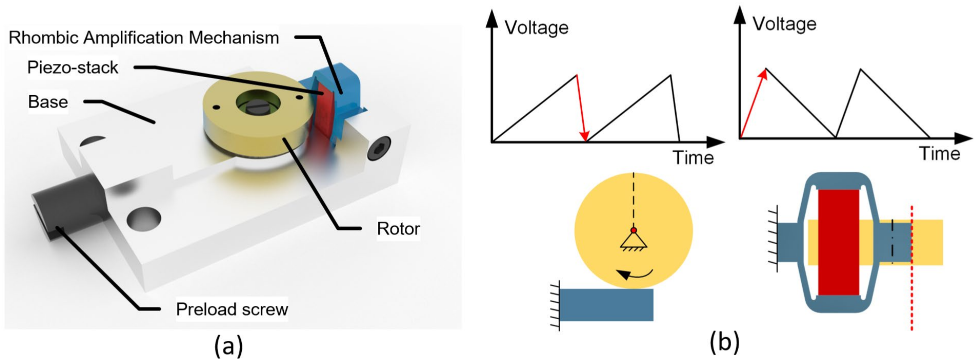

Figure 1: Structure of proposed actuator (a) and driving principle (b)

The configuration of the proposed piezoelectric actuator is shown in Fig. 1(a). The designed prototype is a rotary actuator driven by a single piezoelectric stack (PS) mounted in a RAM. A bronze disk is driven as the rotor of the actuator. The friction force between the RAM and rotor can be adjusted via a preload screw with a spring. The operating principle of the actuator is shown in Fig. 1(b). While PS expands and contracts, the cylinder rotor is subject to frictional force and rotate. And when driven by asymmetric sawtooth wave periodically, which lead to the inertial force periodic exceed stick friction force, rotor rotate step by step. Theoretically, because the motion direction of the driving foot is parallel to the tangential direction and the friction between the contact surfaces is isotropic. The rotor can rotate clockwise or anticlockwise uniformly.

3 Experiments, simulation and discussion on actuator characteristics

To evaluate the performance of actuator, a model of a rotary stick-slip actuator based on the LuGre dynamic friction model was established. As show in figure 2 (a), experimental results of the proposed actuator driven with different voltage, a frequency of 100 Hz were used to compare with simulation. And the result shows acceptable average deviation with a maximum of 4.51% at 30V.

Then the performance improved by proposed RAM was investigation through this simulation method. The results indicate that for driving frequencies from 50 to 500 Hz, the velocity of the actuator with the RAM is always higher than that of the actuator without the RAM, as show in Fig. 2(b). On average, the velocity of the actuator with the RAM is 1.8669 times higher than that of the actuator without the RAM with the same power consumption. Based on the same simulation model, a load torque was added to the subsystem of the rotor to estimate the load capacity of actuator. The simulation results are shown in Fig. 2(b) bottom. That shows rotation step size of the rotor decreased with increasing load torque applied to the actuator. The step size approached zero when the load torque was 21.839 and 13.085 N.mm for the actuators with and without the RAM, respectively. So, the load capacity of the actuator with the RAM is 1.6690 times that of actuator without the RAM. The experiment results also match the simulation results, the prototype achieved average velocity 0.4760 rad/s and load torque 29.35 N.mm in two direction. Thus, the RAM significantly increases the velocity as well as load capacity of a stick-slip actuator.

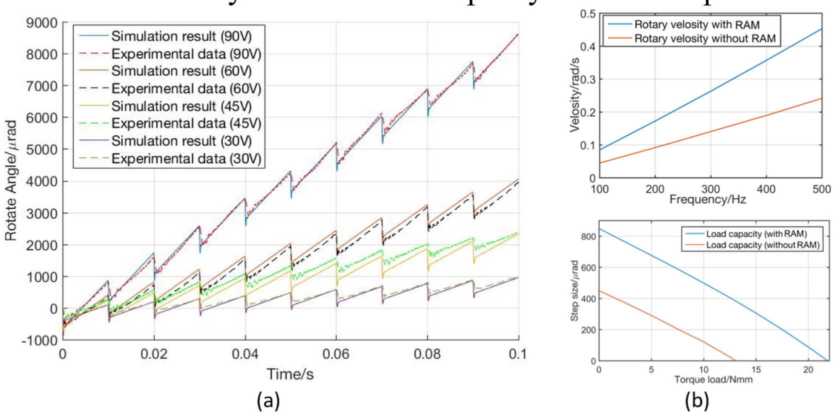

Figure 2: Stick-slip motion in simulation and experiment (a), Preformance improvement by proposed RAM (b)

4 Conclusion

This work demonstrated that unlike a stick-slip actuator with coupling motion, which improves actuator performance in only one direction, the amplified mechanism could improve velocity and load capacity in two directions trough enhance driving stroke and with acceptable loss of stiffness. Based on this, we are considering use different driving method with advantages of long driving stroke in stick-slip actuator, such as electromagnetic force. This research has provided meaningful reference and direction for further study on stick-slip driving mechanism.

References

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[2] Wang J, Qin F, Li L, et al. A linear piezoelectric actuator with high flexibility flexible mechanism designed by the bidirectional parasitic motion principle[J]. Review of Scientific Instruments, 2020, 91(4): 045005.