Study on output characteristics of Offset Twist-roller Frictional Transmission Mechanism

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Abstract. According to the requirements of high resolution and compact space of a rotational-double-prism system, combined with its practical application characteristics of small load and low speed, an offset twist-roller frictional transmission mechanism is proposed. Compared with the clearance elimination gear transmission mechanism, it has the advantages of high output resolution, adjustable reduction ratio, simple structure and low cost. The influence of twist angle on the output characteristics of offset twist-roller frictional transmission mechanism is studied by experiment. The results show that the larger the twist angle, the smaller the driving torque of the driven wheel, the larger the transmission ratio of the mechanism, the larger the fluctuation range of output angular velocity and transmission ratio, and the more unstable the transmission. The transmission ratio of the mechanism in stable transmission is about 30, which is much higher than that in single-stage cylindrical gear drive. The output angular resolution of the mechanism is better than 0.005°, meeting the system requirements. Through the above analysis, it lays a foundation for the application of offset twist-roller frictional transmission mechanism in rotational double prisms system.

1. Introduction

The rotational-double-prism system can change the optical path by rotating independently the two prisms of a common axis, so that it can be used to steer the beams or the Line of Sight. With the advantages of compact structure, high pointing precision, small optical loss and low overall cost, rotational-double-prism system has a wide application prospect in beam scanning, long-range target aiming and tracking.

The transmission design of hollow brushless torque motor or stepper motor and gear reducer is usually used in the transmission of the rotational-double-prism system. The information of prism rotation angle is collected by encoder to realize closed-loop control. Shape size and the transmission aperture are the important mechanical parameters of the rotational-double-prism system. Under the condition of the constraint of the size space, it is often not possible to select a suitable hollow torque motor and hollow encoders to be placed in a narrow annular space. When the transmission scheme of stepper motor and gear reducer is selected, the rotation resolution of prism can not meet the requirement.

In order to solve the contradiction between the large aperture of prism and the small external dimension of the system, as well as the high rotation resolution of prism, a new type of friction drive with offset twist roller is proposed, the driving wheel is a twist roller in the shape of a round table, and the driven wheel is equipped with a refraction prism. In the offset type, the rotating plane of the twist...
roller does not pass through the center of the rotating circle of the driven wheel, and there is a certain offset. Compared with the gear transmission, the offset twist-roller frictional transmission can achieve higher transmission ratio, which meets the requirements of high rotation resolution and compact space for a certain type of rotational-double-prism system, at the same time, it has the advantages of low cost, no lubrication and simple maintenance.

In most related literatures [2-8], the transmission mechanism is composed of a drive shaft and a twist-roller nut which is composed of three uniformly distributed twist rollers, the twist-roller nut is assembled on the friction polished rod, and the twist-roller nut realizes the spiral translation through the friction force. This kind of friction belongs to rolling friction, which has the advantages of smooth transmission and no gap transmission. The ultra-precision positioning of transmission platform can be realized, and the positioning resolution can reach the nanometer level [3].

In order to study the rotary output characteristics of the offset twist-roller frictional transmission mechanism, the transmission mechanism and kinematic characteristics of the mechanism are analyzed, and the force and extrusion deformation in the contact area are analyzed theoretically, the physical prototype experiment on the effect of twist angle on the rotary output characteristics of the system is carried out, which lays a foundation for the structural design and practical application of the transmission.

2. Details of the mechanism and Experiment

2.1. Composition of the transmission mechanism

In the proposed offset twist-roller frictional transmission mechanism, a single twist roller is the driving wheel, the driven wheel adopts the rotating output form, and the axial translation of the driven wheel is limited by the deep groove ball bearing. The included angle between the rotation axis of the driving wheel and the rotation axis of the driven wheel is defined as the twist angle $\alpha$. The positive pressure between the driving wheel and the driven wheel produces small deformation, forming a small contact area at the contact part. There is a certain offset between the horizontal plane where the center of the contact area is located and the horizontal plane where the axis of the driven wheel is located, the offset is $e$ and the deflection angle is $\beta$. The schematic diagram of the mechanism is shown in Figure 1.

![Figure 1. Offset twist-roller frictional transmission mechanism](image)

The twist roller drives the driven wheel by the friction force, which makes the macroscopic slip between the twist roller and the driven wheel. In order to avoid the transmission failure caused by the wear of friction pair, the offset twist-roller frictional transmission mechanism is suitable for low speed and small load conditions, and the friction pair is composed of wear-resistant rubber and metal.

2.2. Experiment Details

The rotating output characteristics of the offset twist-roller frictional transmission mechanism are experimentally studied. The experimental system is built as shown in Figure 2. The driven mechanism is fixed on the Z-translation table, and is fixed on the X-translation table together with the Z-translation table. The driving mechanism, the tri-axial force sensor and the manual rotary table are fixed in turn, and the three parts are fixed on the Y-translation table. The three-way translation table is used to determine the contact position between the twist roller and the driven wheel. The Z-translation table and the tri-
axial force sensor are coordinated to determine and adjust the positive pressure $N$ between the twist roller and the driven wheel. The manual turntable is used to determine and adjust the twist angle $\alpha$.

![Image of the experiment system]

**Figure 2. The experiment system**

The twist roller is a rubber wheel made of aluminum alloy 2A12 as the base material and polyimide as the covering material. The driven wheel is made of aluminum alloy 2A12 with anodized surface. The dimensions and material parameters of twist roller and driven wheel are shown in Table 1.

| Table 1. The parameters of the mechanism |
|-----------------------------------------|
| Twist roller                        | driven wheel                  |
| diameter   | $\Phi25$mm | diameter   | $\Phi93$mm |
| thickness  | 5mm       | thickness  | 6mm       |
| Base/covering material                | 2A12/polyimide                | material   | 2A12      |

The experimental instruments and equipment are shown in Table 2.

| Table 2. Experimental instruments and equipment |
|-----------------------------------------------|
| name                        | type           | specifications                             |
| stepper motor               | 08H2038-050-4AL| Holding torque is 0.3N·m Step angle is 0.12° |
| encoder                     | DFS60A         | resolution is 16 bits                      |
| tri-axial force sensor      | DYDW-004       | measuring range is 5kg sensitivity is 1.5mV/V |
| manual turntable            | RS-917         | index value is 0.01°                        |
| dSpace system               | dSpace1103     | resolution is 12 bits sampling frequency is 1250KHz |

### 3. Results and discussion

Due to the friction torque when the driven wheel rotates, when the twist angle reaches a certain value, the driving torque provided by the twist roller is not enough to overcome the friction torque, and the transmission fails at this time. After many experimental tests, the limit value of twist angle under the existing experimental conditions is 85°. Therefore, the influence of twist angle on the output characteristics of the mechanism is studied by experimental test under the conditions of twist angle of 80°, 82° and 84°.

#### 3.1. Relationship between twist angle and driving torque of driven wheel

When the twist roller runs at a constant angular speed, the driven wheel rotates under the action of driving torque. The test result of driving torque is shown in Figure 3. As can be seen from the diagram, the greater the twist angle, the smaller the driving torque of the driven wheel. When the driving torque is less than the resistance torque of the driven wheel, the driven wheel will stop running.

Due to the influence of the machining precision and surface quality of the twist roller and the driven wheel, the friction between the twist roller and the driven wheel is changed, and the driving torque is fluctuant.
3.2. Effect of twist angle on transmission ratio

The relationship between the twist angle and the transmission ratio is shown in Figure 4. It can be seen from the diagram that with the increase of twist angle, the transmission ratio of the mechanism is larger and the amplitude fluctuation is more violent. Under the existing experimental conditions, when the twist angle is 80°, the transmission is stable and the transmission ratio is about 30, which is much higher than that of the single-stage cylindrical gear transmission mechanism. When the twist angle increases to more than 82°, the transmission ratio amplitude changes sharply, the mechanism cannot transmit the motion smoothly, so the twist angle of the mechanism should be limited to avoid transmission failure.

According to reference [9], in the contact process between the twist roller and the driven wheel, the base of the contact area of the twist roller and the driven wheel metal produce adhesive nodes. Under the action of the driving force, the adhesive nodes are sheared and slide, and new adhesive nodes are generated at the same time. The sliding friction between the twist roller and the driven wheel is the process of alternating the formation and shear of adhesive nodes. Therefore, the micro slip in the contact area leads to the reduction and fluctuation of the angular velocity of the driven wheel. Accordingly, the transmission ratio of the mechanism shows great fluctuation.

3.3. Effect of twist angle on angular position resolution

In the rotational-double-prism system, the rotation resolution of the prism is an important performance index, which directly affects the pointing accuracy of the beam. In order to study the influence of the twist angle on angular position resolution, step signals with fixed number of pulses are input to stepper...
motor at the twist angle of 80˚, 82˚ and 84˚, respectively. The step signal interval is 1 second. The experimental results are shown in Figure 5.

![Figure 5. Experimental results of angular resolution](image)

The experimental results show that the bigger the twist angle is, the smaller the resolution of the output angle is, and the resolution of the mechanism under the three twist angles is lower than 0.009 °, which meets the high-resolution requirements of the rotational-double-prism system. When the twist angle is 84˚, the angular position resolution of the offset twist-roller frictional transmission mechanism is better than 0.005°, which reaches a higher resolution level.

### 4. Conclusion

In this paper, the influence of twist angle on the output characteristics of offset twist-roller frictional transmission mechanism is studied through experiments, and the following conclusions are obtained:

1. The larger the twist angle, the smaller the driving torque of the driven wheel and the larger the transmission ratio of the mechanism, but the greater the fluctuation of the output angular velocity of the driven wheel, the more unstable the transmission;

2. The offset twist-roller frictional transmission mechanism can arrange a larger reduction ratio in a limited space. Under the current experimental conditions, when the twist angle is 80˚, the transmission process is relatively stable and the transmission ratio of the mechanism is about 30, much higher than single-stage cylindrical gear drive;

3. In this type of rotational-double-prism system, the scheme of offset twist-roller frictional transmission mechanism is used, and the angular position resolution of the mechanism can reach 0.005°, which meets the high-resolution requirement.

Taking full advantage of the high resolution of the twist-roller frictional transmission under low load, the offset twist-roller frictional transmission mechanism is proposed under the condition of limited space, it solves the problem that the traditional driving scheme can not meet the requirements of high resolution and compact space of a certain rotational-double-prism system, and has guiding significance for the configuration design and practical application of high resolution transmission mode.

### Acknowledgments

This work was funded by National Key R&D Program of China (Grant No. 2019YFB2004700) and Young Teacher Innovation Research Project (ZN2019-7).

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