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Research on Grease Lubrication of Worm Gearing of Flipping Electric Actuator

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Abstract

For medium and large-power worm gear drives, the amount of grease used is an important factor affecting the transmission effect. Transmission efficiency is a comprehensive index to evaluate the performance of worm gears. In this paper, a reasonable experiment is designed, and the feasibility of the experiment is explained from theoretical knowledge. Finally, through the data of the experiment, the law of the influence of changing the amount of grease used on the transmission efficiency of the worm device for plane motion is summarized.

Keywords

Worm Transmission; Grease Lubrication; Transmission Efficiency.

1. Introduction

The main components of the flipping electric actuator (as shown in Figure 1) include servo motor, reducer, worm gear box (mainly including worm gear, worm, box casing and rolling bearing, etc) and cylinder tube, etc. Due to the plane rotation of the electric actuator along the hinge point at both ends and the unfixed working position of the worm and gear, the conventional oil lubrication method is difficult to maintain the stability and reliability of lubrication and the subsequent maintenance is complex. Therefore, the grease lubrication method is used for specific worm drives[1-3].

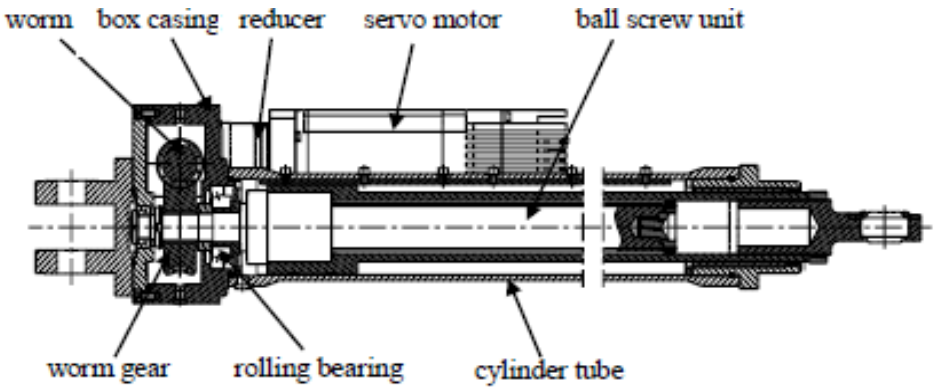

Figure1. Schematic diagram of basic composition of flipping electric actuator

Worm drive has the advantages of large reduction ratio and self-locking under certain conditions, but there are also some problems. For example, the sliding contact surface will produce uncertain energy loss when transferring energy, especially when factors such as the amount of grease used or the input speed of the worm change, the energy loss will produce large fluctuations. Through the experiment, the influence of the above factors on the transmission performance of the worm gear can be conveniently studied, so as to provide a guiding basis for the lubrication design of the worm drive of the turning electric cylinder.

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2. Research on Worm Lubrication Test

There are two main methods for evaluating the quality of worm lubrication, namely, current test method and efficiency test method[4]. This paper uses the efficiency method to verify and test the influence of various factors on the performance of the worm drive.

2.1 Test Method

The test bench is set up. According to Table 1, different amounts of grease are injected into the flipping electric actuator, and the axial load of 60kN is promoted at 600 rpm input speed. The current value of the motor is tested, so as to obtain the influence of the change of grease injection amount on the efficiency fluctuation of worm gear transmission

Table 1. Test factors

Number	Grease amount of worm gear	Input speed of worm	axial load
1	Surface coating	600rpm	60kN
2	1/2 cavity injection		
3	3/4 cavity injection		
4	Full cavity injection		

After determining the optimal amount of grease injection for the device, test the current value of the motor according to the conditions shown in Table 2. The results are compared with the test results of the input speed of the 600rpm worm, and the influence of the change of the input speed of the worm on the fluctuation of the worm drive efficiency is obtained.

Table 2. Test factors

Number	Grease amount of worm gear	Input speed of worm	axial load
1	Optimum injection amount	1000rpm	60kN
2		1500rpm	

Input torque of worm T_i:

$$T_i = k_i I$$

In the formula, k_i is the motor current constant, the parameter value of the motor used by the equipment is 1.6Nm/A. I is the motor input current.

Worm gear output torque T_0:

$$T_0 = \frac{F_a P_L}{2\pi\eta_W}$$

In the formula, F_a is the axial load of the electric actuator, P_L is the lead of the ball screw unit used in the equipment, η_W is the transmission efficiency from worm gear output end to the equipment output end.

Efficiency of worm gear transmission η:

$$\eta = \frac{T_0}{\mathrm{u}T_i} = \frac{F_a P_L}{2\pi u \eta_W k_i I}$$

In the formula, u is the total transmission ratio of the equipment.

2.2 Test bench and test object

The main components of the test bench include installation platform, bracket, pressure sensor, loadinghydraulic cylinder and auxiliary support frame, as shown in the Figure 2.

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Figure 2. Main components of the test bench

The installation platform is the foundation of the test bench. The bracket is used to install and fix the test object and the loading hydraulic cylinder. The loading hydraulic cylinder is used to control the axial load and velocity of the test object, and the pressure sensor is used to monitor the magnitude and fluctuation of the axial load.

The test object is a flipping electric actuator, and its main transmission structure and parameters are shown in Table 3.

Table 3. Main transmission structure and parameter of the flipping electric actuator

Number	Components	Parameters	Remarks
1	Servo motor	Power 3.65kW, current constant 1.6Nm/A	
2	Reducer	Reduction ratio 3:1	
3	Worm gear	Module 4mm, teeth number 45	Material of ZCuAl10Fe3 GB/T5231-2012
4	Worm	Module 4mm, number of threads 1	Material of 45 GB/T699-2015
5	Ball screw unit	Diameter 63mm, lead 32mm	

The Great Wall 7008 high and low temperature grease was used for the lubrication of the transmission mechanism. The grease which produced by HENAN CHANGCHENG SPECIAL GREASE CO.LTD has the characteristics of wide temperature range, moderate viscosity, stable performance and nonvolatile.

3. Test and analysis

Before the test, the flipping electric actuator was run-in and trial-run to make the worm gear mesh better. Due to the relatively poor heat dissipation of grease lubrication, in order to prevent a large amount of heat generated from transmission failure, each test time should not exceed 2 minutes. After each test, wait until the surface temperature of the worm gear box is cooled to about 40°C before performing the next test to ensure the reliability of the test results.

During the test, the dosage of grease shown in Table 1 was added, and the worm input speed was adjusted to 600rpm, 1000rpm and 1500rpm, respectively. The output load was adjusted to about 60kN. In each state, 20 tests were performed, for a total of 120 tests. The current value of the motor during each test is recorded, and the data are processed by Matlab software to obtain the target parameters. The average value of the obtained target parameters is obtained for data analysis.

3.1 Effect of Injection Amount on Current

Within a certain range, as the amount of grease injection increases, the current of the worm drive decreases; when the amount of grease injection is too large, the current of the worm drive increases significantly, as shown in Figure 3.

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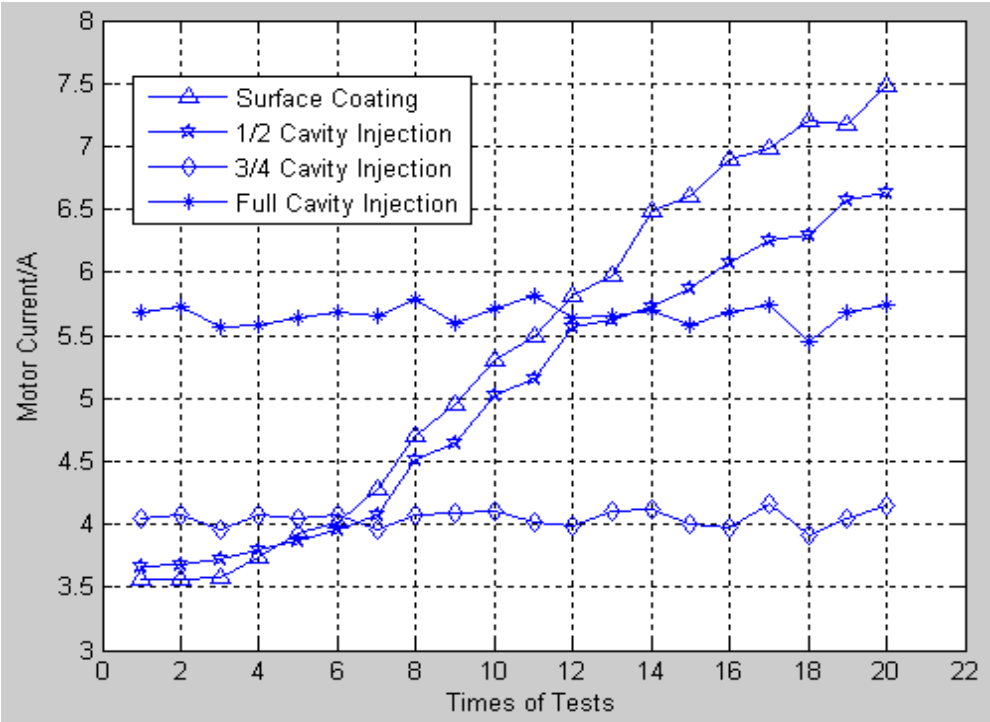

Figure 3. Motor current value for different grease injection

The test phenomena are as follows:

When the worm gear surface is lubricated by surface coating, the motor current increases obviously after 3 to 5 repeated tests at the input speed of 600 rpm, and the motor current increases significantly with the increase of repeated times. The reason is that the meshing area of the worm gear is insufficiently lubricated due to repeated rolling, resulting in "lack of oil".

When 1/2 cavity lubrication, at the same worm input speed, the initial test current of the motor increased slightly relative to the surface coating lubrication, and after about 6 repeated tests, the motor current also increased significantly. And also with the increase in the number of repetitions, the motor current continues to increase. This is because the dosage of the grease increases the stirring loss, so the motor current increases slightly as a whole. The phenomenon of ' oil shortage ' caused by the rolling of the worm gear drive is improved but cannot be completely eliminated. Therefore, with the follow-up test, the balance state of the worm wheel lubrication is broken, the performance of the worm gear drive decreases, and the motor current will continue to rise.

When 3/4 cavity lubrication, at the same worm input speed, the initial test current of the motor increases compared with the surface coating and the 1 / 2 cavity lubrication. However, with the increase of repetition times, the motor current tends to be stable, with an average value of about 4.0 A. This is because the lubrication state of the worm gear has reached a sustainable balance with the further increase in the amount of grease. At the same time, the grease injection further increases the stirring loss of the worm drive, thereby increasing the motor current.

When full cavity lubrication, at the same worm input speed,the initial test current of the motor increases compared with the first three lubrication methods, and the motor current increases significantly. With the increase of the number of repetitions, the motor current basically tends to be stable, and the average value is about 5.7 A. This is because the continuous increase in the dosage of grease has no significant effect on the lubrication state of the worm drive. The lubrication state of the worm drive can maintain a continuous equilibrium state, but the stirring loss of the worm drive is obviously dominant, which significantly increases the current value of the motor.

Therefore, it is determined that among the above-mentioned situations, 3/4 cavity injection is the best lubrication condition.

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3.2 Effect of Worm Input Speed on Current

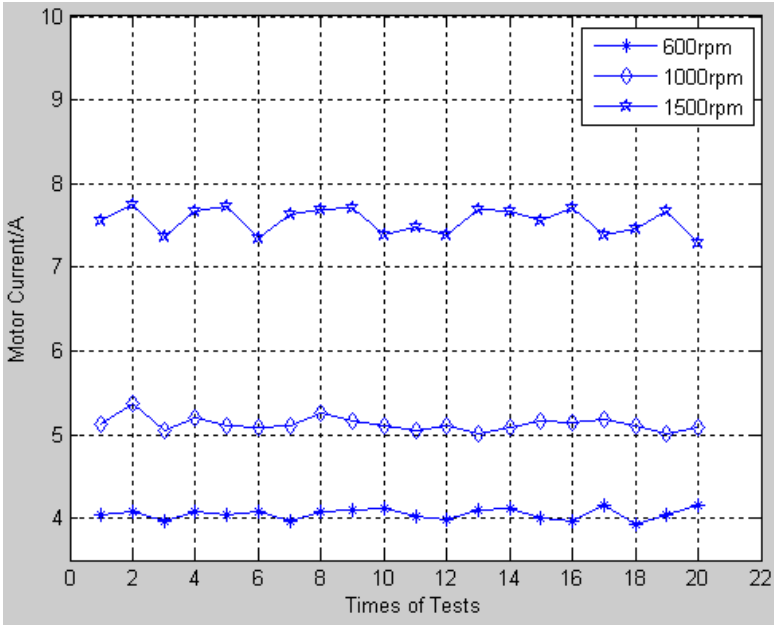

Figure 4. Motor current value at different input speed

The worm drive is tested by changing the input speed of the worm after the 3 / 4 cavity was injected with grease. The test results are shown in Figure 4: With the increase of the input speed of the worm, the current of the motor increases obviously.

The test phenomena are as follows:

As the input speed increases, the motor current gradually increases. When the motor input speed is adjusted to 1000rpm and 1500rpm respectively, the motor current tends to stabilize, and the average current is about 5.1A and 7.5A respectively.

3.3 Efficiency Analysis

Under different grease injection and input speed conditions, the test data are processed to obtain the motor efficiency curve, and the results are shown in Figure 5 and Figure 6.

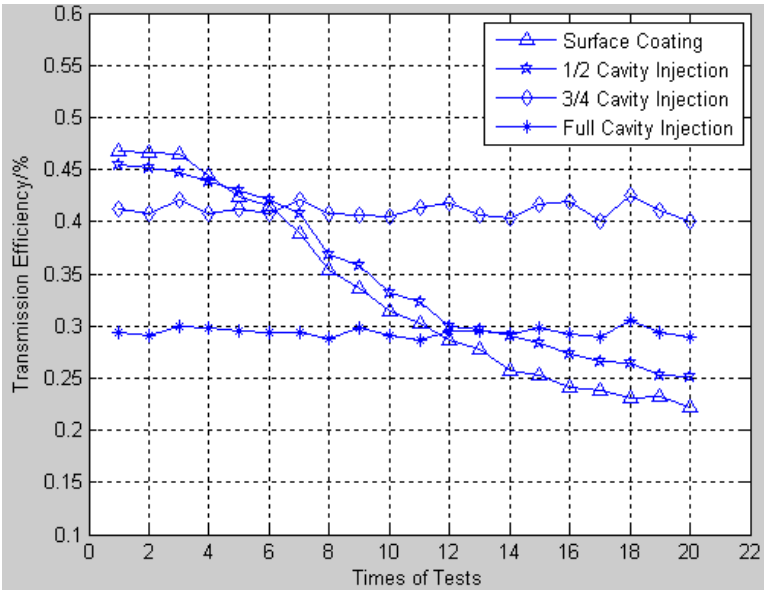

Figure 5. Efficiency value at 600rpm input speed

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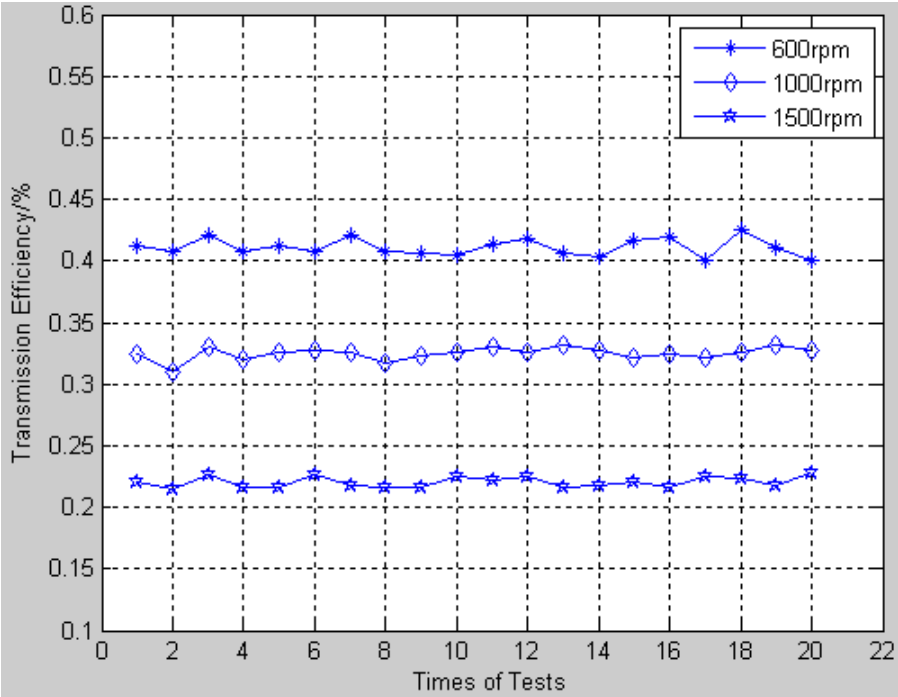

Figure 6. Efficiency value when 3/4 cavity lubrication

It can be seen from Figure 5 that the mechanical efficiency of worm transmission tends to be stable with the increase of the amount of grease injection when the input speed of worm is 600 rpm, but the mechanical efficiency will be reduced when the amount of grease injection is too large.

It can be seen from Figure 6 that the mechanical efficiency of the worm drive decreases with the increase of the input speed when the amount of grease injection is constant.

For a specific worm gear, there is a reasonable amount of grease injection to make the transmission smooth and efficient. When the lubrication is 3/4 cavity grease injection, the worm gear drive has the highest efficiency and is relatively stable.

4. Conclusion

The following conclusions are obtained through tests:

1) For medium and high-power worm gear structures, it is feasible to use grease lubrication;

2) The amount of grease injection is an important factor affecting the transmission efficiency of worm gear pair. For the flipping electric actuator, the optimal amount of grease injection is 3 / 4 cavity;

3) Due to the relatively poor fluidity of grease, the stability of continuous lubrication cannot be guaranteed when the amount of grease is too small;

4) Due to the relatively high viscosity of grease, excessive grease injection will increase the stirring loss during transmission and reduce the mechanical efficiency;

5) When the lubrication is stable, the input speed is an important factor affecting the efficiency of the worm drive. With the increase of the input speed, the efficiency of the worm drive will decrease.

Under certain conditions, it is obtained through research that the fluctuation of the worm transmission efficiency of the flipping electric actuator is affected by the following factors: 1) the amount of grease used; 2) the change of the worm input speed. This provides guidance and reference for the lubrication design of worm drive.

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