Development of a Test Bench for Transmission Efficiency of Small Modulus Worm Helical Gears

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Abstract. Worm helical gear transmission falls between lever transmission and inclined transmission in principle. There is large relative sliding speed between the conjugate tooth surfaces, and the transmission efficiency is low. To accurately grasp the changing law of worm helical gear transmission efficiency and propose an effective efficiency improvement method, this paper designed and built a transmission efficiency test bench for small modulus worm helical gear transmission pair.

1. Introduction

With the continuous development of smart home products, smart medical products and automotive products towards high speed and light weight in recent years, small modulus worm helical gear transmission pair has been increasingly used in these products because of its advantages of big transmission ratio, compact structure, and good manufacturability. Transmission efficiency of the gear pair is one important performance indicator that needs to be measured in gear pair application.

Liu Ge et al. from Chongqing University designed and manufactured a test bench, compared the efficiency of worm helical gear and worm gear pair [1]. Under the specific rotation speed and torque, the former had efficiency close to the latter. After the helical gear was modified, the worm helical gear transmission pair had the same efficiency as the worm gear. Takao Koide et al. Reference [2-4] studied the transmission temperature, meshing temperature and load-bearing characteristics of the plastic helical gear steel worm drive and proposed a prediction method. Wang Bo et al. designed and produced a test bench for efficiency testing, tested the transmission efficiency of worm helical gears under different pressure angles, friction coefficients, helix angles and lubricants to analyze the effect of design parameters on the transmission performance of worm helical gears [5]. Liu Bai et al. proposed the transmission efficiency calculation formula under different loading conditions, and the results showed that the transmission efficiency value changes with the load changing [6]. Peng Zeliang et al. conducted theoretical analysis and experimental tests on the transmission efficiency of involute worms with different transmission ratios from the two aspects: worm transmission meshing efficiency and lubrication, and found that worms with a small transmission ratio and a large lead angle had higher transmission efficiency [7]. Luo Liangqing et al. analyzed the effect of factors such as worm
speed, power, worm lead angle and friction on transmission efficiency, and concluded that reducing the composite curve radius, lowering the roughness, using low elastic modulus materials and selecting appropriate lubrication viscosity are measures to improve transmission efficiency [8]. Li Lei et al. tested and analyzed the transmission efficiency, temperature and friction coefficient changes of steel worm gear with plastic worm wheel, analyzed the effect of point contact form on efficiency, the effect of load on temperature and strain, and the temperature distribution law in the gear pair [9].

To sum up, most of the efficiency tests on worm helical gear transmission pairs target at transmission pairs with standard modulus and number of teeth, and the efficiency law of small modulus transmission pairs has not been investigated. Based on the above theory, this paper designs and develops a small modulus worm helical gear transmission efficiency test bench

2. Test Bench Plan
The test bench takes small modulus helical gear transmission pairs of different models as the test object, which is also applicable to other small cross-axis gear pairs. The main task is to test the transmission efficiency of worm helical gear pairs. The test is required to acquire the input and output torque parameters of the tested worm helical gear pair in real time through the industrial computer, adjust the rotation speed of the motor at the input end of the tested transmission pair and the load torque at the output end, and ensure that the measured torque signal is synchronously acquired and processed to guarantee the accuracy of curves and indicators. The overall design model of the transmission efficiency test bench and the device connection mode are shown in Figure 1.

![Three-dimensional schematic diagram of the test bench](image)

Figure 1. Three-dimensional schematic diagram of the test bench

The drive motor is fixed on the motor base through a bolt connection, and the motor output shaft is connected to the input end of the high-speed end torque sensor through a coupling; the high-speed end torque sensor is fixed on the sensor mounting base, and its output end is connected to the input end of the tested transmission pair through coupling; the input ends of the transmission pair are respectively fixed on the bearing bracket, the output ends are respectively fixed on the bearing bracket, and the output end is connected to the low-speed end torque sensor through a coupling; the low-speed end torque sensor is fixed on the sensor mounting base, the output end is connected with the magnetic powder brake through a coupling, and the magnetic powder brake is fixed on the base.

To ensure the location information of the input end and output end base of the test bench, the input end motor base, sensor base and bearing bracket are fixed on the input end stand, the output end bearing bracket, sensor base and magnetic powder brake base are fixed on the output stand. To adapt to the different shaft lengths and center distances of the test objects, the test bench is designed to be adjustable. By adjusting the adjustment components on the adjustment stand, the input and output end stands can be lifted in the height direction, moved and fixed along the axis respectively. At the same time, an electronic dial indicator is equipped for height adjustment, which can accurately control the adjustment amount to ensure the center distance of the transmission pair.

According to the expected test object, and the principles of integration and light weight of the test system, the corresponding test equipment and test instruments are selected. Test instruments and meters should be calibrated and standardized in accordance with relevant national standards and
regulations, and the accuracy should meet the test requirements. The drive motor is a DC brushless servo motor with small size, high rotation speed, large output torque and high control accuracy, which is equipped with a dedicated drive. The torque sensor is a small, high-precision strain gauge torque sensor, which is equipped with the corresponding data acquisition card.

The magnetic powder brake adjusts the torque on the load side. The electrical control system is mainly composed of industrial computer, data acquisition box and various other electrical components, which are assembled in the test system control cabinet. The finally assembled efficiency test platform is shown in Figure 2.

Figure 2. Efficiency test bench (1- Drive motor; 2- Input torque sensor; 3- Output torque sensor; 4- Magnetic powder brake; 5- Lifting platform; 6-Mobile platform; 7- Marble platform; 8-Mobile platform; 9-Mobile platform)

3. Test Bench Hardware Debugging

3.1. Levelness adjustment of input and output stand and platform

The input and output stand is used as the reference plane for the installation of subsequent components, whose levelness will seriously affect the installation accuracy of subsequent components. The factors that affect stand levelness can be divided into two major aspects. On the one hand, the two ends of the sliding table under the stand is not level and cause error accumulation, or the different pressing forces of the bolts at each corner of the stand cause deflection; On the other hand, the upper end surface and the lower cross-section of the stand are not parallel due to processing errors and processing deformations. The adjustment method is to mount the dial indicator on a marble platform, push the stand to move along the axis through the lower guide rail, observe the dial indicator reading in the moving process to judge the stand levelness; then place the dial indicator on another stand, through the movement of the other stand along the axis, observe the dial indicator reading during the movement. Judge the stand levelness according to the reading, add copper of a certain thickness to the end where the reading is higher, repeat the above steps after adding copper, add and remove the copper according to the reading until the stand levelness meets the requirement.

The input end stand levelness is improved from 0.7mm before adjustment to 0.01mm after adjustment, and the output end stand levelness is improved from 0.55mm before adjustment to 0.02mm after adjustment, so the stand levelness has been greatly improved.

3.2. Adjustment of the parallelism between the moving track on the stand and the moving direction of the stand

The moving track on the stand is used for horizontal movement of the bearing bracket along the axis of the input and output ends, which is composed of multiple guide rails. Parallelism of the moving track will affect the subsequent torque sensor installation on the tested transmission pair and the shaft angle between the transmission pairs. The adjustment method is to mount the dial indicator on the
marble platform, push the stand to move along the axis through the lower guide rail, and observe the dial indicator reading during the movement to judge the guide rail parallelism. Judge the rail parallelism by the reading, we loosen the bolts that fix the guide rail, slightly adjust the guide rail position, compact the two ends of the guide rail, and repeat the above steps until the rail parallelism meets the requirement.

The parallelism of the guide rails on the input stand is improved from 0.32mm before adjustment to 0.02mm after adjustment, and the levelness of the output end stand is improved from 0.20mm before adjustment to 0.01mm after adjustment, so parallelism of the guide rail on the stand has been greatly improved.

3.3. Perpendicularity adjustment of the input end axis and the output end axis of the test bench
The perpendicularity of the input end axis and the output end axis of the test bench cannot be measured by conventional measuring instruments. Only a three-coordinate measuring instrument can be used to measure the perpendicularity of the rail on the input end and output end stand. Acquire a series of points on the input and output end rails through the three-coordinate measuring instrument probe, and then fit the acquired points into a straight line, calculate the angle of the input end line and the output end line in the three-coordinate measuring instrument software. If the angle of the two straight lines is smaller than the expected value, loosen the bolts that fix the rail, fit the rail through the L-shaped work piece and fine-tune the rail position. After adjustment, repeat the above steps until perpendicularity of the two rails meets the requirement.

Figure 3. shows the process of track parallelism measurement by a three-coordinate measuring instrument. The perpendicularity of the guide rail on the input and output end stand is improved from 89°50′52″ before adjustment to 89°58′49″ after adjustment, so parallelism of the guide rail on the stand has been improved.

3.4. Coaxiality adjustment of shaft components on the input and output axis
It is a difficult process to adjust the coaxiality of shaft components on the input and output axis, which is because the test bench has compact size, the shaft length of each component is very short, and conventional instruments cannot measure the entire circumference of the shaft section. First, a three-coordinate measuring instrument is used to measure the coaxiality of shaft parts on the input and output axes by the common axis method. Measure multiple cross-sectional circles on the measured element and the reference element, and then construct a 3D straight line as a common axis with the center of these circles. The diameter of each circle can be inconsistent. Then, calculate the coaxiality of reference cylinder and the measured cylinder with regard to the common axis, take the maximum value as the coaxiality of the part. This common axis is similar to a simulated mandrel, so this method approaches the actual part assembly process.

However, after the adjustment, due to the small gap between the motor output shaft and the high-speed end torque sensor input shaft during the actual assembly process, the sensor needs to be removed and reinstalled during the coupling installation process, which damages the original
coaxiality. The coaxiality error is then compensated through elastic coupling, which thus leads to great noise during the test bench operation. Finally, a tooling is fabricated to ensure the coaxiality of the shaft components on the input and output axis, and the elastic coupling between the motor output shaft and the high-speed end torque sensor input shaft is replaced with a rigid coupling. Take the measured transmission pair axis on the input end stand guide rail as the reference, and sequentially adjust the torque sensor axis at the high-speed end—the rigid coupling—the motor output shaft to ensure the coaxiality of shaft components on the input end axis. The coaxiality adjustment of the shaft component on the output end axis is similar to this. Through the replacement of sleeve tooling and rigid coupling, the vibration and noise problems of the test bench during operation are greatly alleviated, and the test accuracy is also increased.

4. Software design and debugging of test bench

4.1. Measurement and control signal processing

The torque sensor used in the test bench is a strain gauge torque sensor, the voltage signal is in a linear relationship with the rated torque, and the torque measured by the torque sensor can be obtained through the voltage output signal. However, because the torque sensor range is too small, it is extremely sensitive to torque fluctuations and vibrations. After installation and operation within the concentricity deviation range required by the sensor, the input torque still has great fluctuations. To suppress and prevent interference signals, it is necessary to process the torque signal.

In the process of sensor data collection, abnormal values will be generated due to various interferences. Filtering is divided into circuit filtering and algorithm filtering. Arithmetic average filter is selected, and N sampling values are continuously taken for arithmetic average operation. When the N value is high, the signal smoothness is high, but the sensitivity is low. After comparison of various arithmetic average filtering calculations, two average filtering algorithms are selected for experiment.

The traditional average filtering algorithm requires a large amount of memory. Also, considering that the torque may change in the actual test process, average filtering of all data by this algorithm does not meet the needs of the test. The queue average algorithm can quicken the selection of a certain number of values for arithmetic average operation, and has faster response to signal changes than the traditional average filtering algorithm. Finally, this algorithm is selected to process the torque signal, and the serial port subroutine of LabVIEW is compiled, as shown in Figure 4.

![Figure 4. Serial port subroutine](transmission
efficiency
curve)

4.2. Software debugging of test bench

Open the software and enter the main interface of the measurement and control system of the test bench. The system then automatically initializes. When the industrial computer establishes communication with the motor control system and signal acquisition system, the system status will be displayed on the user interface as normal, and then the relevant parameters can be set, including transmission ratio and motor speed. When there is some error or unexpected circumstance in the
system operation, the indicator in the system status bar will display drive failure. Click the motor stop button on the interface to exit the program operation or press the emergency stop switch on the electric control cabinet. The main window interface of the measurement and control program of the test bench is shown in Figure 5.

![Small modulus worm helical gear transmission efficiency test system](image)

**Figure 5.** The main window interface of the measurement and control program of the test bench

The display and control window of the main interface of the measurement and control software of the test bench can be roughly divided into drive unit, test data unit and system status unit. The drive unit supports setting of relevant parameters through the keyboard and mouse to realize running state control of the servo motor, such as input speed. Set the transmission ratio of the test transmission pair for calculation of transmission efficiency. The test system has access to the input and output torque of the transmission pair to be tested through the torque sensor and the data acquisition card detection. After calculation and conversion through the LabVIEW program, it is displayed on the main interface in two ways: graph and digital frame. The loading control of the magnetic powder brake achieves direct adjustment of the exciting current value through the tension controller.

For implementation of the transmission efficiency test, the test system calculates and processes the measured torque parameters, motor speed parameters, and transmission ratio parameters through the LabVIEW program, then displays the torque and transmission efficiency of the tested reducer on the main interface. The display of input, output torque and transmission efficiency has two modes: digital block diagram and waveform diagram. The waveform diagram is the change curve of the parameter with time, and the data display window shows the size of the real-time value of the parameter. All running state parameters and real-time curves can be automatically saved as data files in Excel or txt formats, and real-time graphs can also be exported as simplified images in multiple formats, thus providing a basis for the production, analysis and research of related transmission pairs.

5. Conclusion

   (1) According to the characteristics of the small modulus worm helical gear transmission pair, a small modulus worm helical gear transmission efficiency test bench was designed and developed.

   (2) The levelness, parallelism, perpendicularity and coaxiality of the test bench were measured and adjusted to achieve higher accuracy.

   (3) The software measurement and control part of the test bench was compiled, signal processed and debugged.

Acknowledgments

This article is one of the phased achievements of National Key R&D Program (2018YFB2001701) and Chongqing Natural Science Foundation(cstc2018jcyjAX0301).

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