Research on the New Type of Error Detection Platform for Photoelectric Encoder

Kun Li¹,², Guohua Cao¹³*, Hongchang Ding¹³ and Han Hou¹

¹School of Mechanical and Electric Engineering, Changchun University of Science and Technology, Changchun, 130022, China.
²Engineering Training Center, Changchun Institute of Technology, Changchun, 130012, China.
³Chongqing Research Institute, Changchun University of Science and Technology, Chongqing, 401135, China.
*Corresponding author’s e-mail: caogh@cust.edu.cn

Abstract. In order to realize the error detection of high precision optical encoder, an error detection method of optical encoder based on optical continuous closed loop (OCCL) was proposed, by the principle of small angle measurement of photoelectric autocollimator and single reflector. Firstly, the configuration of the OCCL error detection platform for optical encoder is designed. Then, the error detection principle of the OCCL optical encoder is analyzed. Finally, the OCCL photoelectric encoder error detection system is established, and the calibration auto-collimator and the regular 23-hedral polyhedron are used to calibrate the accuracy of the detection system. The experimental results show that the new photoelectric encoder error detection platform is frequent, convenient, stable and reliable, and the accuracy of the detection platform can reach 1.64″ in the rated working speed range, which can meet the requirements of high precision (2″) and 360° full circle continuous error detection for the encoder.

1. Introduction
As a kind of angular displacement sensor, photoelectric encoder is widely used in the defense industry, aerospace, precision of ultra-precision manufacturing measuring instruments such as the shaft of rotation position measurement[1-3]. However, the photoelectric encoder inevitably has the systematic error and the random error caused by the uneven grating scale, the eccentricity of the code disk installation and the photoelectric processing circuit error. Therefore, high precision encoder error detection technology is a necessary condition to achieve high accuracy and high resolution of angle displacement sensor. The research on error detection method of photoelectric encoder is the key to improve the accuracy of error detection system of photoelectric encoder[4-5].

2. Configuration design and working principle

2.1. Platform configuration design
The high precision photoelectric encoder error detection platform is a vertical independent biaxial structure, which is mainly composed of a test turntable and a small optical angle measurement module. The test turntable for the vertical twin screw structure, is divided into internal shaft and external shaft,
and two shaft independence movement, the internal shaft system is mainly composed of influenza virus coder, torque motor, grating ruler, bearing and mirror etc all around, the encoder under inspection is coaxial with the quadrangle reflector. And external shaft system is mainly composed of torque motor, grating ruler, bearing and shaft of mesa etc all around, the outer shell of the encoder to be inspected is fixed with the outer shaft table. And the motion range of internal and external shafting is continuously infinite, which can realize the continuous detection of 360° for the encoder to be inspected. The bottom part of the turntable is the base part, which mainly realizes the level and azimuth adjustment of the turntable, and the detection platform prevents the precision optical vibration isolation platform. The optical small angle measurement module is composed of high precision photoelectric autocollimator and four-side mirror, which mainly realizes the precision measurement of small angle with high precision. Among them, the internal structure of the accuracy detection platform is shown in Figure 1.

![Figure 1. Structure of precision detection platform.](image)

2.2. Working Principle of the Platform

The precision photoelectric encoder error detection platform controls the internal and external biaxial movement[6-7]. Firstly, the outer shaft is locked, and the inner shaft rotates angle α within the detection range of the photoelectric autocollimator. At this time, the coaxially connected encoder to be examined and the four mirrors rotate angle α, then photoelectric autocollimator detects the rotation of the system angle α₁, and the output of the encoder to be checked angle α₁`, and the encoder angle error (α₁-α₁`). After that, the outer shaft is unlocked and the inner shaft is locked, the system controls the reverse rotation of the internal and external biaxial angle -α to return to the initial zero position, and the inner shaft under the action of locking remains in relative position. Secondly, the outer shaft is locked, and the inner shaft rotates angle α within the detection range of the photoelectric autocollimator again. At this time, the coaxially connected encoder to be examined and the four mirrors rotate angle α, then photoelectric autocollimator detects the rotation of the system angle α₂, and the output of the encoder to be checked angle α₂`, and the encoder angle error (α₂-α₂`). In this way, the continuous error detection of the whole circumference of the high precision encoder with the photoelectric autocollimator as the optical closed loop is realized within the range of 360° of the whole circle[8].

3. Experimental verification of biaxial structure turntable

3.1. Precision analysis of biaxial structure turntable

Based on the error analysis of the biaxial structure and the optimized simulation of the biaxial error detection turntable, the machining, assembly and detection of the biaxial structure turntable are carried
out according to the accuracy requirements of the error analysis of the biaxial turntable. The reliability and rationality of the design of the biaxial turntable are verified by using the photoelectric autocollimator and the single reflector to form the precision detection and calibration platform for the rotary accuracy test of the optical detection system. Among them, the precision detection and calibration platform of the biaxial turntable is shown in Figure 2.

![Figure 2. Accuracy detection and calibration platform.](image)

On the basis of precision calibration platform of physical prototype testing, every 30 ° to the positive and negative direction of rotation angular error repeatedly sampling, with positive and negative direction of rotation error of Fourier harmonic analysis for error of original data, with positive and negative direction of rotation error of composite modified Fourier harmonic analysis and sparse decomposition for mixed fitting data[9], the outer axis rotation accuracy 1.014", inner shaft rotation accuracy 1.138", it can be known that the rotation accuracy of the double axis turntable is 1.524". Among them, the comparison distribution diagram of the rotation accuracy of the outer shaft and the inner shaft is shown in Figure 3 and Figure 4.

![Figure 3. Rotation accuracy curve of outer shaft.](image)  
![Figure 4. Rotation accuracy curve of inner shaft.](image)

After the actual measurement of the precision detection calibration platform, the accuracy of the biaxial error detection turntable is 1.524", which means the mechanical structure error of the biaxial turntable is 1.524".

### 3.2. Calibration of error detection platform

Based on the biaxial structural error analysis and the optimized biaxial angular displacement error measurement system turntable, the biaxial turntable was machined, assembled and tested with specific precision according to the accuracy requirements of error analysis[10]. The measurement and control system of the precision detection platform based on the continuous closed loop of the photoelectric autocollimator and the position feedback control of the biaxial encoder was used to debug the testing
software of the encoder detection device of the detection platform, and the technical indicators of the error detection platform were tested. Among them, the biaxial error detection calibration turntable and error curve were shown in Figure 5 and Figure 6.

![Figure 5. Error detection calibration turntable.](image1)

![Figure 6. Calibration error curve of biaxial precision.](image2)

By using high precision photoelectric autocollimator (level 2) and the regular polyhedron (23 sides) to detect system calibration, known from the analysis of experimental data, not for error compensation before operation, biaxial photoelectric encoder error detection system within the scope of rated speed precision can reach 1.64", consistent with the results of biaxial test reasoning, the biaxial structure satisfies the requirement of high precision detection.

4. Conclusion

In order to realize the error detection of high precision optical encoder, an error detection method of optical encoder based on the OCCL was proposed by the principle of small angle measurement of photoelectric autocollimator and single reflector. The control system of photoelectric encoder error detection is created by using the detection platform. The accuracy of the detection platform is calibrated by using the autocollimator and the regular 23-hedral polyhedron, the accuracy of the detection platform can reach 1.64" within the range of rated working speed, which is basically consistent with the theoretical calculation results. The new photoelectric encoder error detection system has the advantages of high detection accuracy, low cost, not limited by angle reference, full range detection and strong adaptability to industrial environment, meeting the requirements of high precision, full circle continuous error detection for encoder.

Acknowledgments

This research was financially supported by the National Key R&D Program of China (Grant NO. 2017YFF0105304), Science and Technology Development Plan Project of Jilin Province (Grant NO. 20200401117GX) and Youth Fund project of Changchun Institute of Technology (NO.320210006).

References

[1] Yu, H., Wang Q.H., Lu, X.R. (2016) Dynamic precision calibration of photoelectric encoder error detection turntable. Optics and Precision Engineering., 26: 2699-2704.
[2] Wang, Y., Lin, B., Dongye G.H. (2019) Design and Finite Element Optimization Analysis of Accessory Ultrasonic Vibration Table. Journal of Beijing University of Aeronautics and Astronautics., 45: 1589-1596.
[3] Yu, H., Wang Q.H., Liang, L.H. (2015) Dynamic error detection of small photoelectric encoder. Transactions of Beijing Institute of Technology., 35: 1090-1095.
[4] Dong, K.Y., Shi, M.Q., Liu, J. (2019) Automatic precision detection system of photoelectric encoder. Chinese Journal of Sensors and Actuators., 32: 463-468.
[5] Liu, X.S., Wang Q.H., Yang, S.W. (2017) Automatic error detection system of incremental encoder based on FPGA. Instrument Technique and Sensor., 64: 62-65.
[6] Wang, Q.F., Wang, H., Xie, Z.J. (2017) Compensation of angular indexing error of precision turntable. Optics and Precision Engineering., 25: 2165-2172.
[7] Li, J.K., Feng, Q.B., Bao, C.C. (2019) Measurement method and error analysis of rotation angle positioning error. Infrared and Laser Engineering., 48: 0217001-1-6.

[8] Li, K., Ding, H.C., Cao, G.H., Hou, H. (2020) Research on high precision error measurement system of angular displacements based on reciprocal roll angles. Opt. Eng., 59: 124110-1-10.

[9] Moazeni, M., Behbahani, M., Khedmati, M. (2020) Single-replicate longitudinal data analysis in the presence of multiple instrumental measurement., 2: 106-117.

[10] Chen, J.X., Lin, S.W., Zhou, X. (2016) A comprehensive error analysis method for the geometric error of multi-axis machine tool. International Journal of Machine Tools and Manufacture., 106: 56-66.