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CIRCULAR GRATING ECCENTRIC TESTING AND ERROR COMPENSATION FOR ROBOT JOINT USING DOUBLE READING HEAD

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ABSTRACT

The circular grating is used as the measurement standard component in the robot joint-angle test system, however the measurement error is inevitable due to the installation eccentricity. In order to correct the measurement error, both the compensation model and eccentric detection test are needed to be investigated. Firstly, the compensation model about angular error is deduced according to the relationship between the angular error and the eccentric parameters. Secondly, we proposed a method to detect the grating eccentricity and eccentric direction by using double reading head. The eccentric parameters of grating is obtained from the Lissajous plot, which is generated by the composite signals. Finally, the experiment results show that the amended angular accuracy has been greatly improved.

Keywords: *Robot Joint-Angle Measurement, Circular Grating, Error Compensation, Eccentricity Ranging, Eccentric Direction Test*

1. INTRODUCTION

For the robot motion control system, the servo motors are usually used as the driving component [1], while the various types of sensors (i.e. vision sensor [2], torque sensor, velocity sensor and position sensor [3], etc.) are usually used as the measuring components. The robot joint-angle test system can be used to measure the output accuracy of the robot joint-angle position, and provide research basis for the transmission characteristics of the joint flexible parts and the internal sensor calibration [3]. The circular gratings are used as angle position measurement component and as circular of the joint angle accuracy measurement. Measuring accuracy of the grating directly decides the performance of the joint-angle test system and application range. However, an eccentricity is inevitable between the gratings and joint-shaft during installation, and the eccentricity leads to measuring angle error. Therefore, the grating measuring angle need be amended to guarantee the measuring accuracy.

At present, the amending research for circular grating measuring angle mainly concentrates on the measurement error caused by the eccentricity. In [4], Guo analyzes the effect of eccentricity on grating measuring angle. In [5] and [6], Yu and Zhang analyze the expression of grating measuring angle error by using Fourier series expansion method and realize the measurement of grating measuring angle error through 23 faces polygon calibration method. Wang and Gao identify and amend the grating installation eccentricity error based on the simulated annealing algorithm, one can see [7] and [8]. In [9], Zhu uses four reading heads method to eliminate the influence of grating encoder eccentricity and vibration. However, the present work do not discuss that how to measure eccentric error (eccentricity and eccentric direction) under the difficult assembly and adjustment condition.

In the robot joint-angle test system, the measured joint need reinstallation for the different requirements, thus the eccentric parameters will be seriously changed. Using calibration and identification method to amending the grating involves high cost, long time and complex operation, and this method can not be applied to the measurement system where the shaft changes repeatedly. In order to measure the eccentric error more efficiently and conveniently and to amend the grating measuring angle, this paper proposed a method to detect the grating eccentricity and

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eccentric direction by using double reading head. And using the grating eccentric measuring angle error model, the measurement system can be amended.

2. ROBOT JOINT-ANGLE TEST SYSTEM

The robot joint-angle test system can test the positioning accuracy, output shaft angle hysteresis and velocity performance of flexible joints under different loads. The hardware system of the joint-angle test system (as shown in Figure 1) includes robot joint, torque sensor, load, grating encoder, upper computer and data acquisition card, etc.. The grating is connected with joint-shaft to measure the output-angle. The joint output is connected with torque sensor through coupler, and the load is connected with the other end of torque sensor.

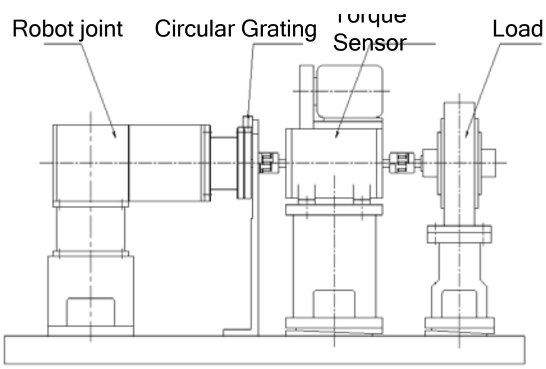

Fig.1 Framework Of Robot Joint-Angle Test System

Robot joint is a high precision servo system, and the position of single joint is controlled in the range of 12 arc-seconds, so the high measuring requirements about the circular grating is needed. During the actual measurement, the relative eccentricity between the grating and measured shaft affects the measurement accuracy seriously. It is difficult to assemble and adjust the gratings, and the eccentricity can not be detected by microscope. Furthermore, the eccentric parameters between the grating and joint-shaft will change when the joint is reinstalled. At this time, the test efficiency will decrease if using calibration method. Hence, an efficient and convenient method should be proposed to measure the grating eccentric error and amend the angle-error caused by the eccentricity.

3. AMEND RESEARCH OF GRATING MEASURING ANGLE ERROR CAUSED BY ECCENTRICITY

When using gratings to measure rotation motion, the angle position error is period. The sources of grating measuring angle error mainly includes grating installation eccentric error, bearing radial error and grating stripe error, etc.. We can use high precision bearing and grating to ensure the range of bearing radial error and grating stripe error. The main source of error comes from grating installation eccentric error, which affects the system measuring accuracy to a large extent. During the installation, geometric center of grating and rotation center of measuring shaft don't coincide, which causes eccentric error. Eccentric error is a regular system error, and the error changes with angle periodic, thus amended compensation can be used to eliminate the eccentric error [10, 11]. The following thesis will discuss the relationship between eccentric error and measuring angle.

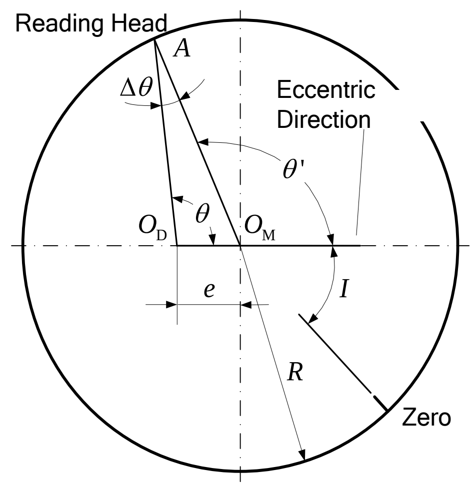

Fig.2 Angular Error Resulting From An Eccentricity Error

As shown in figure 2, analyzing the angle error caused by eccentricity, O_M is grating geometric center, O_D is measuring shaft rotation center after installation, e is eccentricity, R is the grating optical radius, taking eccentric direction O_DO_M as reference, the angle scanned by photoelectric sensor is θ'. Due to eccentricity, actual angle of grating is θ, thus eccentric measuring error $\Delta\theta$ is

$$\Delta\theta = \theta - \theta' \quad (1)$$

According to geometric relationship, we can obtain

$$\tan\Delta\theta = \frac{e \cdot \sin\theta'}{R + e\cos\theta'} \quad (2)$$

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After installing gratings and measuring shaft, there is a fixed phase relationship between grating zero line direction and eccentric direction, which is eccentric phase angle I , zero line rotation angle, which is the readout angle of sensor θ_s

$$\theta_S = \theta' + I \tag{3}$$

Bring (3) into (2), the relationship between θ_s and $\Delta\theta$ is

$$\Delta\theta = \arctan\frac{e\cdot\sin(\theta_S - I)}{R + e\cdot\cos(\theta_S - I)} \tag{4}$$

When $\sin(\theta_S - I) = 1$, the measuring error caused by eccentricity gets its maximum, and maximal error value is

$$\Delta\theta_{\max} = \arctan\frac{e}{R} \tag{5}$$

According the above analysis, the measuring error caused by eccentricity changes with rotation angle, error value $\Delta\theta$ can be expressed as function of measuring shaft rotation angle θ_s . Expression (5) is a model of error compensation, measuring angle error is related to two constant parameters, eccentricity and eccentric direction. We can amend grating measuring angle error through these two parameters.

4. GRATING ECCENTRIC TEST RESEARCH

To obtain eccentric error angle compensation formula completely, the grating eccentric parameters need to be tested. According to grating measuring angle principle, monochromatic light emitted by laser generates interference fringe through grid line of grating. After photoelectric receiver receives interference pattern optical signal, sinusoidal signal can be observed in the oscilloscope. When grating is eccentric, the sinusoidal signals tested by reading heads of different position in circumferential direction at same moment have phase difference [12]. Considering this feature, we can test the grating eccentricity and eccentric direction according to composition of sinusoidal signals of different phases.

Two photoelectric reading heads collect stripe signals. Reading head-1 and head-2 are installed in position A_1, A_2 respectively, taking rotation center O_D as center (shown in Figure 3). Due to the eccentricity between grating geometric center and rotation shaft, it leads to different grating numbers of reading head-1 and head-2 through the same time, which means two photoelectric reading heads don't pass same length in optical circumference at same time. As a result, the tested sinusoidal signals of reading head-1 and head-2 have different frequency and phase.

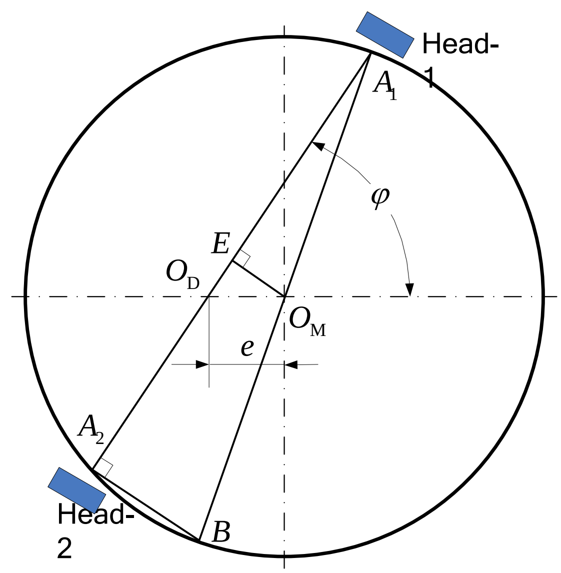

Fig.3 Illustration Of Two Sensor Testing Eccentricity Error

Next make further analysis of relationship between eccentricity and received signal phase difference. When shaft rotates along a fixed direction, the length difference that reading head-1 and head-2 pass in optical circumference is $\overset{\frown}{A_2B}$. According to Small Angle Approximation Theory, $\overset{\frown}{A_2B} \approx A_2B$, $O_M E \perp A_1A_2$. According to geometric similarity shown in Figure 3, length difference $\overset{\frown}{A_2B}$ can be expressed as

$$\overset{\frown}{A_2B} \approx 2O_M E = 2e\cdot\sin\varphi \tag{6}$$

Where φ is the angle between eccentric direction and line $\overrightarrow{A_1A_2}$.

The corresponding angle value of length difference $\overset{\frown}{A_2B}$ in the electric stripe signal cycle is the phase difference of tested sinusoidal signals two reading heads. And the relative phase difference of

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received signals of reading head-1 and head-2 can be expressed as

$$\Delta\psi_{12} = 360° \cdot \frac{2e \cdot \sin\varphi}{d} \qquad (7)$$

Where d is grating pitch, 360° represents the angle value in a electric stripe signal cycle. The phase difference between the reading head-1 and head-2 changes with shaft angle.

When the shaft rotates a circle, the eccentric distance difference of reading head-1 and head-2 will reach the extreme point twice (shown in Figure 4), which correspond respectively the two points that receiver-2 reads when eccentric direction crosses $\overrightarrow{A_1A_2}$. From minimum, grating rotates 180° anti-clockwise to reach maximum, during which the total phase difference that two reading heads have read is $\Delta\psi$. Transforming the expression further, the formula of eccentricity e is

$$e = \frac{\Delta\psi}{4 \cdot 360°} \times d \qquad (8)$$

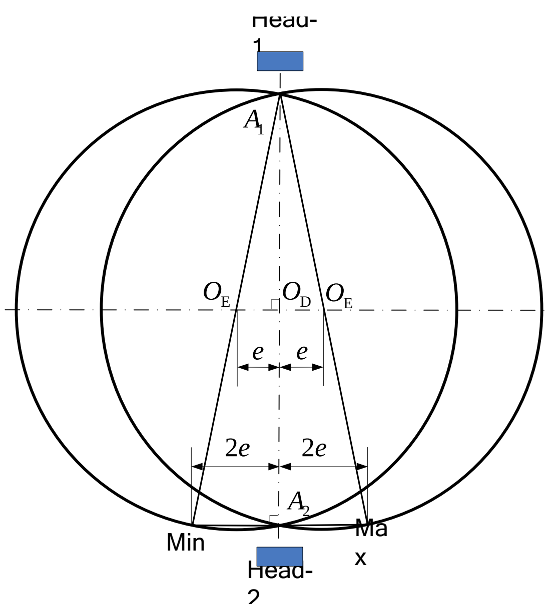

Fig.4 Illustration of Eccentric Extreme Position

From the moment when reading head-2 has read the extreme point, the grating continues to rotate 90 degree, the eccentric direction will be consistent with the direction of $\overrightarrow{A_1A_2}$. Therefore, after acquiring the phase extreme point from the oscilloscope, the eccentric direction of grating can be determined according to the orthogonal relation,.

Thus, contrasting the composite signal of two reading heads can calculate the phase difference of diameter position signals after a circle, thus determining the eccentricity and eccentric direction. Putting eccentricity e and eccentric phase angle ψ into formula (4), amending formula of measuring angle error caused by eccentricity can be obtained completely.

5. MEASURING EXPERIMENT AND RESULTS

5.1 Eccentric Error Measuring Experiment

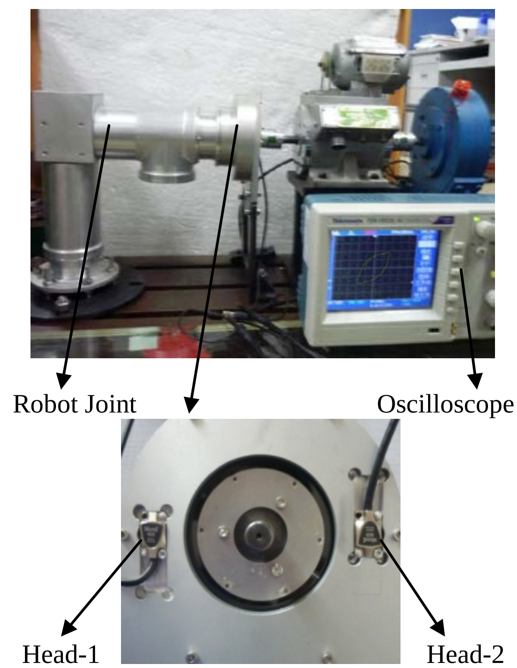

Fig.5 Experiment of Eccentricity Error Detection

Reading head-1 and head-2 are installed in the sensor holder of manipulator joint test system grating. Receiver gets its electricity through a 5v regulated power supply, and channel-1 and channel-2 of oscilloscope are connected to the signal output of reading head-1 and head-2 respectively (shown in Figure 5).

Electric signals transformed by reading head-1and head-2 are composed as Lissajous plot through two channels of oscilloscope. Based on Lissajous plot, the corresponding phase difference (the same sinusoidal signal frequency is required) can be read. The method is as follows:

X is the distance between two intersections of plot and horizontal axis, X_0 is projection length of

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plot on the horizontal axis, $X / X_0 = \omega$, and the phase difference $\Delta\psi = \arcsin(w)$.

The method of obtaining phase difference is as follows. Firstly, the eccentric extreme position need to be decided. Since the measured shaft rotates along one direction, we can observe the motion trail of Lissajous plot. When the motion direction changes, record the minimum point and the phase difference $\Delta\psi_{\min}$, then get the maximum point and the phase difference $\Delta\psi_{\max}$. After getting the extreme point, record the changing cycles of Lissajous plot during the rotation, namely the periodicity in the phase difference n. Through the above record, use the following formula to calculate the eccentricity

$$e = \frac{(\Delta\psi_{\max} + 360n - \Delta\psi_{\min})}{4 \times 360^{\circ}} \times d \qquad (9)$$

Using the MicroE-R10851 grating in the experiment, and the pitch is 20μm. Through the measurement and calculation, the grating eccentricity after installation is 6.9μm, and the eccentric phase angle is 34.96º. Taking these eccentric parameters into formula (4), formula of error compensation caused by eccentricity can be obtained completely.

5.2 Measurement Experiment Verification

In order to verify improvement effect on the measurement accuracy of robot joint-angle test system after amending the grating eccentric measuring angle error. Putting the error compensation formula into the error amending program of test software, take the angle as amending angle. Taking measuring angle of 24-prism as standard angle (shown in Figure 6), measure the angle every 15°, and record the standard angle value, the measuring value before amending , the measuring angle after amending, respectively.

The contrast of measuring angle error before and after the amending is shown in Figure 6. From Figure 6, the plot of the measuring angle error before amending is a sine curve which means grating measuring angle error mainly is system error. After eccentric error amending, the measuring angle error range is apparently reduced. One can see that the grating angle-error before and after amending are respectively 173.4 arc-seconds and 38.2 arc-seconds, which means the error is decreased nearly 78%. Thus, the circular grating measurement precision is improved greatly.

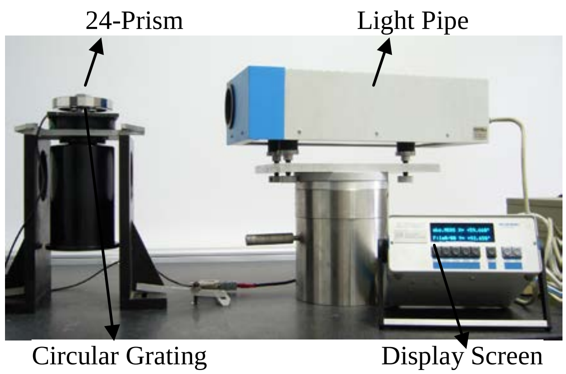
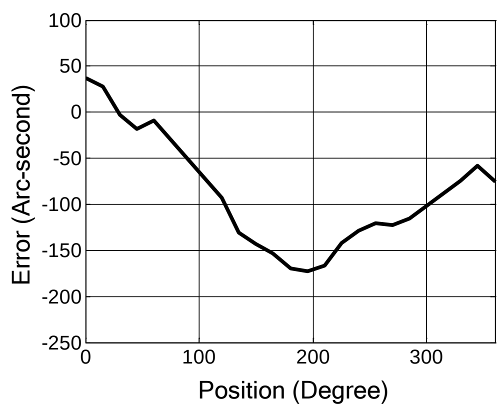
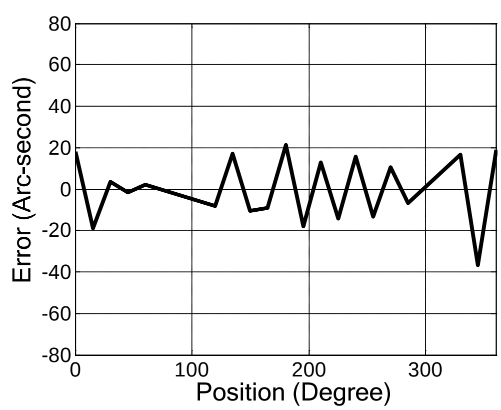


Fig.6 The 24-Prism Measurement System



(a) The Grating Angle-Error Before Amending



(b) The Grating Angle-Error After Amending

Fig.7 Angular Error Before/After Compensation

6. CONCLUSION

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Measuring angle error caused by grating installation eccentricity is an important factor which affects grating measurement accuracy. The paper studies the relationship between eccentric parameters and grating measuring angle, and deduces compensation formula of grating measuring angle error caused by eccentricity. This error compensation model has generality and can be applied to other photoelectric measurement angle system. This paper puts forward a method of testing grating eccentricity and eccentric direction through phase difference of two reading heads' received signals, and gets the measuring angle error compensation formula. Without increasing large test instrument, amend the grating measuring angle in a short time. The results of measurement experiment show that grating measurement error has been decreased nearly 5 times after amending, and measuring accuracy satisfies requirements of joint test system.

7. ACKNOWLEDGMENTS

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