Accuracy Analysis of RV Reducer Eccentric Shaft Follow-Up Grinder

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Abstract. Eccentric shaft follow-up grinder is the core equipment in the process chain of eccentric shaft machining. In the process of grinding, the establishment of the kinematic model and the determination of the kinematic relationship of the C-X axis follow-up grinding directly affect the quality of the grinding process, and there are many error factors in the grinding process. It is very important to analyze the influence law of these factors on the quality of the workpiece. Through the mechanism of the error in the process of machining, which is caused by the change of X coordinate position, head frame rotation and wheel center eccentricity, the geometric relationship is established to solve the problem. The MATLAB simulation is carried out to find out the source of the error, so as to lay the foundation for the subsequent error compensation and achieve the purpose of improving the machining accuracy.

1. Introduction

With the advent of intelligent manufacturing industry, industrial robots are gradually used in various fields, and their development quality and level largely represent a country’s industrial development level [1]. As the core part of RV Reducer at the joint of industrial robot [2], eccentric shaft is shown in Fig. 1, which is generally used for low-speed or static adjustment position, requiring small volume and high machining accuracy. Therefore, its processing quality and efficiency directly restrict the development of industrial robots. RV reducer eccentric shaft follow-up grinder is the working master machine for grinding eccentric shaft, which requires higher accuracy. However, the influence of grinding machine’s own wear and human factor error is far higher than the influence of part surface roughness error, which has become the main factor affecting the machining quality of the whole part, so effective measures must be taken to solve it [3-5].

![Figure 1. 3D model of RV Reducer eccentric shaft](image-url)
In this paper, the error sources of grinding machine in the process of machining are summarized, and the mechanism of error in the process of machining from the change of X coordinate position, the change of headstock rotation and the change of wheel center eccentricity is discussed. The geometric relationship is established to solve the problem, and MATLAB simulation is carried out to find out the source of error and pave the way for error compensation, which is applied to practical production.

2. Error caused by eccentric installation of grinding wheel

In the process of grinding, the grinding wheel rack moves back and forth with a large stroke, and the position of grinding cut point changes all the time, so it is necessary to analyze the eccentricity error of the initial installation of the grinding wheel, and obtain its impact on the surface quality of the workpiece.

The deviation between the actual installation position and the ideal position of the grinding wheel center may occur in any direction in the plane, and the size is uncertain. Here, a random deviation vector with the error size of \( \Delta H \) is assumed, and then the influence of the vector on the grinding accuracy in the whole cycle is analyzed. As shown in Fig. 2.

In the Fig. 2, \( O_1 \) is the ideal installation position of the grinding wheel, \( O_1N \) is any eccentric vector, its angle with the horizontal positive direction is \( \alpha \), and point \( n \) is the eccentric position of the grinding wheel center. Analysis of geometric relations:

\[
MN = MO_1 + O_1N^2 - 2 \cdot MO_1 \cdot O_1N \cdot \cos(180^\circ - \alpha - \beta) = (R_2 + R_3)^2 + \Delta H^2 + 2 \cdot (R_2 + R_3) \cdot \Delta H \cdot \cos(\alpha + \beta)
\]  
\[
\beta = \arcsin \left( \frac{R \sin \theta}{R_2 + R_3} \right)
\]

The position error caused by theoretical grinding point and eccentric state is \( \Delta e \): 

\[\Delta e = MN - MO_1 \]  

Substituting Eq. (2) into Eq. (3):

\[\Delta e = \sqrt{\left(R_2 + R_3 \right)^2 + \Delta H^2 + 2 \cdot (R_2 + R_3) \cdot \Delta H \cdot \cos(\alpha + \beta)} - R_2 - R_3 \]  

According to the given parameters and the eccentricity vector length of the grinding wheel center is 0.02mm, the rotation range is within, and the off axis error Fig. 3 is obtained by computer simulation according to the above formula in the process of one circle rotation of the workpiece.
3. Error caused by position change of X axis

The grinding wheel rack drives the grinding wheel to rotate with the spindle for reciprocating motion. In the large travel range, the deviation between the position of the grinding wheel center on the X axis and the ideal position will be caused by the machine tool guide rail or motor servo, which will cause the off axis profile error. When the actual position of X lags $\Delta x$, the error formation mechanism is shown in Fig. 4.

In the triangle $AO_1O_2$, according to cosine theorem:

$$\text{AO}_O^2 = \text{AO}_1^2 + \text{O}_I\text{O}_2^2 - 2 \cdot \text{AO}_1 \cdot \text{O}_I\text{O}_2 \cdot \cos \left(180^\circ - \beta \right)$$

(5)

Where $\text{AO}_I = R_2 + R_3$, $O_1O_2 = \Delta x$, $\beta = \arcsin \left(\frac{R_1 \sin \theta}{R_2 + R_3}\right)$

The off axis machining error caused by the center lag of grinding wheel is recorded as $e$,

$$e = \sqrt{(R_2 + R_3)^2 + \Delta x^2 - 2 \cdot (R_2 + R_3) \cdot \Delta x \cdot \cos \left(180^\circ - \beta \right)} - R_2 - R_3$$

(6)

$$\Delta x = R_1 \cos (\theta - \Delta \theta) + \sqrt{(R_2 + R_3)^2 - R_1^2 \sin^2 (\theta - \Delta \theta) - R_1 \cos (\theta) - \sqrt{(R_2 + R_3)^2 - R_1^2 \sin^2 (\theta) \right)}$$

(7)

Where, $\Delta \theta$ is the change of crankshaft angle corresponding to the wheel center $\Delta x$.

$R_1 = 200$ (mm), $R_2 = 80$ (mm), $R_3 = 400$ (mm) and the variation of the angle of the eccentric axis with the center lag of the grinding wheel is taken as $0.05^\circ$ and $0.1^\circ$, the simulation diagram of the deviation error within one circle of the workpiece rotation is shown in Fig. 5.

Similarly, it can analyze the error influence when the X coordinate position is advanced. Fig. 6 shows the error generation mechanism when the grinding wheel coordinate X is ahead of the ideal machining coordinate. The expression of off axis machining error $E$ is as follows:

$$e = \sqrt{(R_2 + R_3)^2 + \Delta x^2 - 2 \cdot (R_2 + R_3) \cdot \Delta x \cdot \cos \left(180^\circ - \beta \right)} - R_2 - R_3$$
Substituting the above assumed eccentric shaft size, within the range of one revolution of the eccentric shaft, the change of the crankshaft angle caused by the advance of the grinding wheel center is taken as 0.05° and 0.1°, and the machining error of the eccentric shaft is simulated, as shown in Fig. 7.

In conclusion, the change of the X coordinate of the grinding wheel center will directly affect the geometric dimension of the connecting rod journal after machining, and at the most significant 90° and 270° positions, the error direction is opposite, which will lead to the roundness deviation of the connecting rod journal.

4. Conclusion
This paper summarizes and summarizes the error source analysis of the follow-up grinding machine, mainly introduces the mechanism of the error in the process of processing caused by the change of the X coordinate position, the change of the headstock rotation and the change of the wheel center eccentricity. Through the geometric modeling analysis and the MATLAB simulation, the influence of the error is visualized, which lays the foundation for the error compensation, and finds out the main error sources as follows:

1) When the eccentric position of the grinding wheel is in the horizontal direction, the error of the connecting rod journal is obviously affected;

2) The change of the X coordinate position of the grinding wheel center will directly affect the geometric dimension of the connecting rod journal after machining, and at the most significant 90° and
270° position, the direction of error is opposite, which will lead to the roundness deviation of the connecting rod journal;

3) In the whole cycle motion, the error caused by the rotation lag of the headstock is the biggest when it is 0° ~ 180°. The results provide the necessary conditions for the practical production, the development of specific error compensation technology of eccentric shaft grinder, and the improvement of the production quality and efficiency of machining eccentric shaft.

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