Accuracy Measuring For the RV Reducer Cycloid Gear and Manufacturing Error Analysis

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Abstract: RV reducer is an important function part of industrial robot joints. The cycloid gear measuring problem is the key part of high precision RV reducer manufacturing. A brief introduction to the forming principle and formulas of RV reducer cycloid tooth contour. A new method for measuring the contour accuracy of RV reducer cycloid gear is proposed in the paper, which is used coordinate measuring machine to detect the tooth contour error of cycloid gear. The measuring method, steps and precautions in measuring are discussed in detail. Proposing a data processing and verification program and the cycloid gear manufacturing error is also analyzed. The detection method is certified to meet the application requirements through actual measurement.

Introduction

With the continuous development of science and technology, especially these years, all kinds of advanced technology are applied to the mechanical field, the machinery manufacturing industry automation level enhances unceasingly. At the same time, in China and some developing countries, the advantage of cheap labor has been gradually disappearing. Automation has become the direction of manufacturing industry. The robot industry is developing rapidly. RV reducer is an important function part of industrial robot joints. But different from the ordinary planetary transmission form, which include the sharing of the crank shaft, cycloid gear, needle tooth of a shell and a support structure closed planetary transmission, compared with other ordinary Deceleration mode, this mode can be smaller, transmission ratio is bigger, more efficient, more smooth transmission. In order to make machining cycloidal wheel meets the requirements, you must have a set of standard test method. This paper takes the RV reducer cycloid gear as the research object, the paper expounds the research on its detection methods, and some analysis on the causes of error.

Tooth profile of cycloid gear

Forming principle of cycloid tooth contour (see figure 1).As shown, the process of generating cycloidal tooth profile need two circles, there is a fixed circle, we call it the base circle, the radius is set to r′ c, another round circumscribed in the base circle, we call it a happening circle. Happening circle around the base circle rolling, radius set to r' p, the eccentricity of two circles a =r′ p - r′ c, when making pure roll round, select point B on the dynamic circle, its trajectory will be BB 'B "B"' B1, the curve is called epicycloid; at this time ,Assuming that there is a point M fixed with the happening circle, and this point is located outside of the circle, then the point’s trajectory will be MM 'M "M"' M1 and we call it short of epicycloid.

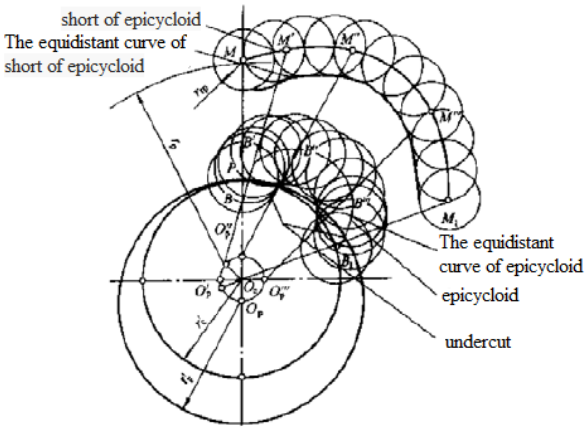


Fig.1 forming principle of cycloid tooth contour

The formula of cycloidal tooth profile [1]

Epicycloid formula:

$$\begin{cases} x_c = \left[r_p - r_{rp}S^{-\frac{1}{2}}\right] cos[(1-i^H)\varphi] - \left[a - k_1 r_{rp} S^{-\frac{1}{2}}\right] cos(i^H\varphi) \\ y_c = \left[r_p - r_{rp}S^{-\frac{1}{2}}\right] sin[(1-i^H)\varphi] + \left[a - k_1 r_{rp} S^{-\frac{1}{2}}\right] sin(i^H\varphi) \end{cases} \quad (1)$$

In this formula:

r_p denotes the center circle radius of needle wheel（mm）;

r_{rp} denotes the radius of needle tooth（mm）;

z_b denotes the number of Needle tooth;

i^H denotes the relative transmission ratio of cycloid gear and needle wheel, $i^H=z_b/z_a$, z_a denotes the number of cycloidal gear teeth;

a denotes the eccentricity of the needle wheel center and cycloid gear center（mm）;

S is the function of k_1、φ: $S = 1 + k_1^2 - 2k_1 \cos\varphi$;

φ denotes relative angle of cycloid gear tooth tumbler with center to a needle radius vector, namely phase angle of meshing (rad), φ changes from 0-2π form a complete tooth profile.

When we give the basic needle wheel center circle radius, the radius of needle tooth, tooth number data etc. and then determine a series of Angle (0-360 °), we can draw a series of cycloid outline point coordinates. By a certain amount of repair, we can draw a cycloidal tooth profile equation.

The tooth profile accuracy measuring.

Because the RV reducer cycloidal tooth's profile processing precision is very high, choosing to use high precision coordinate measuring machine to do contour error detection. Coordinates measuring machine has an advantage in dimensional accuracy and precision of geometric accuracy and the contour measurement.

Coordinate measuring machine have high requirements for the environment, such as the temperature, which has a large extent affect on the measurement result, under normal circumstances, coordinate measuring machine needs to be placed in the laboratory of the constant temperature and humidity measurements, on the other hand, when measured with coordinate measuring machine, the temperature of testing part should be taken into account, also need to consider no matter the temperature of the testing part stay too high or too low, can affect the results of the measurement.so before measurement, need to put testing part in measuring room for a period of time before measurement.

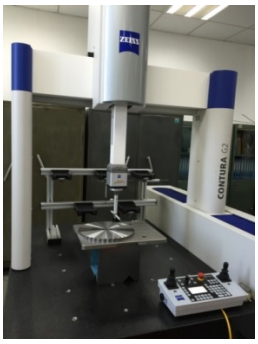


Fig.2 coordinate measuring machine

Coordinates measuring choose the Zeiss (see figure 2), high precision, more convenient, but scanning can only scan in round way due to software limitations, so the system will think that it is a circle measurement, the first step is the preparing work before measure: probe calibration; The second step is to establish a coordinate system: first, choosing several points (at least three)using coordinate measuring head on one side of the cycloid gear ,XOY plane is determined, and then choose a few points in the central cylinder to find a circle, make the center of the circle projected to plane XOY to establish a coordinate system;

The third step is to establish measurement procedures: choose a few points on the teeth crest of cycloid gear, generate a circle, set as the default measure circle of the system and select spacing or measurement points, generated path scanning measurement automatically. Finally a series of probe center coordinate can be output; The fourth step is Data processing: here are two kinds of processing methods, one is put these coordinate points into the actual coordinates on the contour through algorithm, then import CAD software and compared with the theory of tooth profile, another kind is the theory of tooth profile after algorithm find the probe center coordinates, compared with the measured values, both two methods can found the tooth profile error location. Then analyzing and correcting. Using VC to write a cycloid gear profile curve points output program (see figure 3),

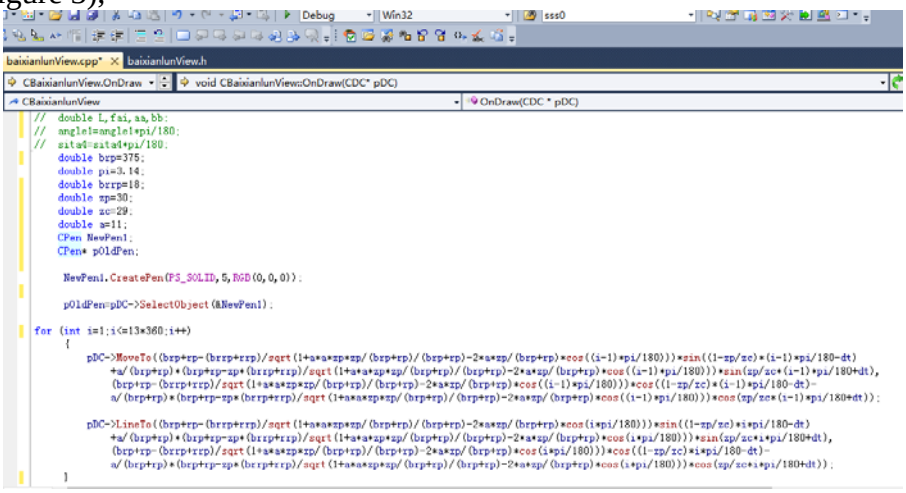
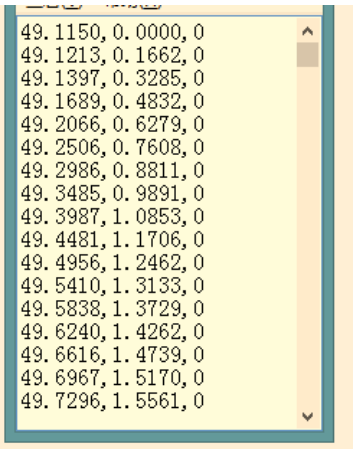


Fig.3 Cycloid gear contour program

Choose output points, generate TXT file (see figure 4),



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49.1150, 0.0000, 0
49.1213, 0.1662, 0
49.1397, 0.3285, 0
49.1689, 0.4832, 0
49.2066, 0.6279, 0
49.2506, 0.7608, 0
49.2986, 0.8811, 0
49.3485, 0.9891, 0
49.3987, 1.0853, 0
49.4481, 1.1706, 0
49.4956, 1.2462, 0
49.5410, 1.3133, 0
49.5838, 1.3729, 0
49.6240, 1.4262, 0
49.6616, 1.4739, 0
49.6967, 1.5170, 0
49.7296, 1.5561, 0
```

Fig.4 Output contour point

Using AutoCAD software reads the file data, then use spline curve to connect these points, draw out the curve and get theoretical contour line, put coordinates measurement data into AutoCAD, and analyze contour error compared with theoretical contour line (as shown in figure 5).

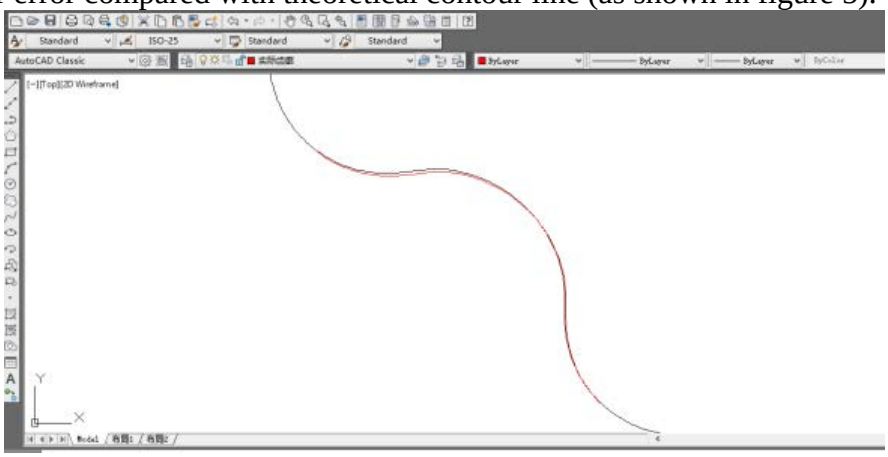

Fig.5 analyzing contour error

Measurement is an important section of manufacturing, without standard and accuracy, make things waste, the tooth contour of cycloid gear has a high accuracy requirement, in the range of micron, measuring need to do a few times, eliminate the effects of random error.

Error analysis.

First of all, coordinate itself exist error, a few microns; Spline curve fitting in using AutoCAD software also can have certain error.

In terms of machining cycloid gear it is divided into the following several parts, we need to establish a mathematical model for the analysis on some key parts of the machine tool, through model analysis and calculation to find out causes of error and amended, on the purpose of optimizing tooth profile and improving machining accuracy.

The error of grinding wheel shape. Because it is forming processing, the shape of the grinding wheel directly determines the cycloid gear contour shape, the error of the grinding wheel shape direct reaction on the cycloid gear, and the shape error of grinding wheel is determined by the diamond wheel. When repairing the grinding wheel, diamond wheel don’t move, grinding wheel move along the axial direction, move along the outline of a tooth in radial direction, it involves the machine tool error, straight axis positioning precision error, when grinding wheel move along the axial direction, if the location accuracy cannot meet the requirements, the wheel contour deformation occurs, eventually led to the cycloid gear contour errors.

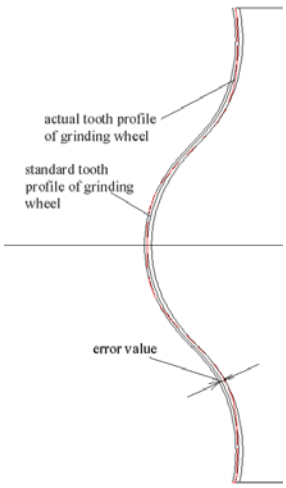

Fig.6 analyzing grinding wheel shape error

Distance error of Grinding center and spindle center. In the actual process of cycloid gear machining, there is a certain error between grinding center to machine tool spindle center, because of the error, the relative position of the grinding wheel to the spindle center changed, thus the effect is equivalent to moving distance modification, under the effect of the error, the actual tooth profile of cycloid gear and theoretical tooth profile cannot be perfectly matched, and therefore produced a certain number of tooth contour error.

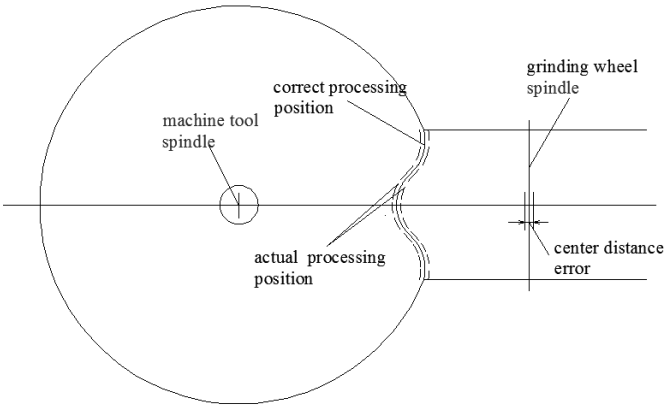

Fig.7 The center distance error analysis

Grinding wheel face, the radial runout error. In machining process, due to the grinding wheel loading, grinding force, grinding wheel will be presented on the condition of the axial and radial runout. When axial runout, axial tooth will be ground more parts and the cycloid gear tooth thickness decreased, lateral clearance increases, and when grinding wheel radial runout, height of tooth will increase, resulting in contour error.

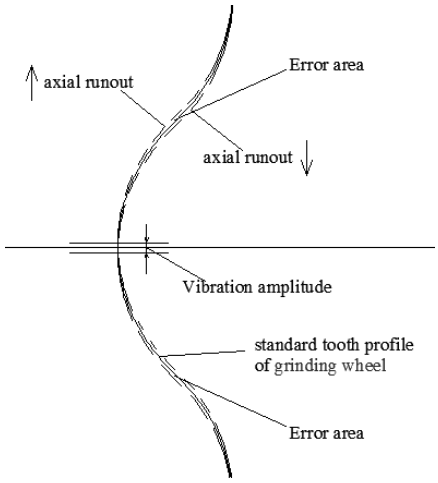

Fig.8 axial runout of grinding wheel error analysis

Machine tool spindle eccentricity error, fixture error. When spindle is eccentric, cycloid gear workpiece center rotate around the spindle. When cycloid gear workpiece center rotate to the processing side of grinding wheel, it will grind out more. When the workpiece center rotate to the other, grinding amount will be reduced, eventually led to the circular degree of the processed cycloid gear cannot meet the requirements.

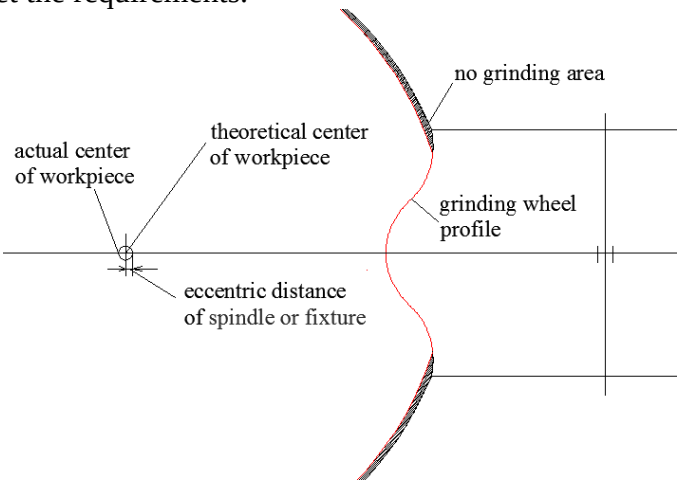

Fig.9 eccentricity error analysis

At present, the cycloidal gear contour error of the project has not been unified national standards; we can consult involute gear standard to make the following definition. Tooth profile error: on the end section of the whole tooth profile scope, finding out two tooth profile equidistant curve with the design profile which include actual tooth profile recently, measure the normal direction of two curves. Cycloidal tooth profile error range can be seeing through these values.

Summary

Cycloid gear is the key parts in the RV reducer with high machining precision requirement, only using scientific method can we obtain valid data, using coordinate measuring machine can meet our requirements. But the analysis process after measurement is more tedious, it will be more efficient with special measuring instrument like gear measuring. Test results were in order to serve the processing and manufacturing better, we can find out the problem to modify and optimize process through error analysis, then improving product quality in the end.

Acknowledgments

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