Analysis of the Key Structures of RV Reducer Based on Finite Element Method

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Abstract. In this paper, key structures of the RV reducer were calculated by finite element method respectively, including the stress and deformation of cycloidal-pin wheel and eccentric shaft. The results show that the contact stress and equivalent stress of cycloidal-pin wheel and eccentric shaft are far less than the strength of materials. It means the strength is not the main consideration of design and manufacture. The stiffness of eccentric shaft is less than the cycloidal-pin wheel, which had a great influence on the transmission accuracy of the machine. In order to improve the rigidity so as to improve the transmission accuracy of gear reducer machine, the modification methods and modification should be chosen to design by the deformation.

1. Introduction

Cycloidal-pin wheel reducer was invented by L. Braren¹, which was improved by the Nabtesco company. Then the RV (Rotate Vector) gear reducer was invented. The RV reducer is composed of planetary gear transmission and cycloidal-pin wheel transmission, which is widely used in industrial robots, machine tools, assembly equipment, handling equipment and other fields. It has more meshing gear at the same time and is small, lightweight, high stiffness, high overload etc. Due to small clearance, rotational vibration and inertia, it has good speed performance, which can realize smooth running and get the correct location accuracy²³.

In theory, cycloid gear and pin gear are completely tangent and there is no gap between each other. However, because of the manufacturing error and installation error, in order to install the cycloid gear and pin gear smoothly, the teeth profile have been modified, which causing the clearance and idle and decreasing the torsional stiffness and transmission accuracy of the RV reducer. In view of the transmission accuracy problem of RV reducer, domestic and international scholars have much in-depth research. Naren Kumar⁴ have established the single-stage elastic torsional flexibility of cycloidal-pin wheel transmission and torque transfer efficiency by static experiment and finite element analysis, which helps to realize the dynamic optimization design of cycloidal-pin wheel transmission and standardization. Blanche⁵⁶ studied the single rotary precision of the cycloid-pin gear planetary reducer with pure geometry method, including torsional vibration causing by backlash and fluctuating ratio of speed, deduced several kinds of calculation formulas about machining error and backlash caused by installation error, and used the CAD method to find out the relationship between the tooth gap, the fluctuating ratio of speed and the torsional vibration. Although this method is rigorous and the conclusion has guidance, it only considers the single stage and single cycloid gear transmission accuracy, which does not apply to the RV reducer composing of planetary gear transmission,
cycloidal-pin wheel transmission and several cranks. Ta-Shi Lai\cite{7,8} used the finite element method to calculate the contact force and contact deformation about the theory of cycloid tooth profile. There is large error about the calculation result because the actual tooth profile was modified. In view of the present study, the structure of the RV reducer was analyzed through the finite element method in this paper, especially about the cycloidal-pin wheel and the eccentric shaft. Base on the analysis of stress and deformation calculation results, the influence of accuracy has been clear between the key components and the whole RV reducer machine, providing technical reference for precision gear reducer design, manufacture and application.

2. Finite Element simulation analysis of the RV reducer

2.1 The construction of a finite element model

The RV-40E is a kind of RV reducer widely used. In this paper, it was selected to be the research object. The 3D model of the RV-40E was established in the Pro/E. Then import the model into ANSYS15.0. Because of the irregular structure components, the RV reducer cannot be divided by using hexahedron mesh. Therefore, the tetrahedron elements were used to divide the model. Finally, the model was divided into 1055948 nodes and 1055948 elements. The material parameters of components of the RV reducer are shown in Table 1.

| Material    | Young’s modulus(GPa) | Poisson’s ratio | Yield limit(MPa) |
|-------------|----------------------|----------------|------------------|
| Cycloid gear| 20CrMo               | 211            | 0.292            | 700              |
| pin         | 20CrMo               | 211            | 0.292            | 700              |
| Pin wheel   | 20CrMo               | 211            | 0.292            | 700              |
| Eccentric shaft | GCr15     | 219            | 0.3              | 518              |
| Eccentric bearing | 20CrMo | 211            | 0.292            | 700              |
| others      | 20CrMo               | 211            | 0.292            | 700              |

The output flange works as the output. So attach the fixed constraint to the pin wheel. Pin and pin wheel were attached cylindrical constraint, restraining it rotate only along the circumferential direction. The input and output flanges connected through the pin hole. Then attached constraints on them to restrain they rotate only along the center axis of rotation. Cycloidal gear and pin, cycloid gear and eccentric bearing, eccentric bearing and eccentric shaft, planetary gear and sun gear, planetary gear and eccentric shaft are all set as the frictional contact relationship between each other. The friction coefficient was set as 0.15. In this paper, the selected type of RV reducer’s output torque was 572 Nm. Converting to the input shaft, it is 4.77 Nm. Converting to the cycloid wheel, it is 14.3 Nm. Converting to the eccentric shaft, it is 7.15 Nm. The established finite element model is shown in Figure 1.

![Figure 1](image_url)
2.2 Cycloidal-pin wheel and eccentric shaft mechanism simulation Results

The first level planetary gear mechanism in the RV reducer is the traditional involute gear. There are much research about involute gear has been relatively mature. The related research results can be directly applied to the analysis of the first transmission mechanism, which was no longer to be analyzed in this paper. The output flange’s stiffness is large. Some literature has already carried out comparatively detailed analysis. So it was no longer to be analyzed in this paper too. Submit the finite element model of the RV reducer to the ANSYS solver to calculate and get the contact stress nephogram, equivalent stress nephogram and equivalent deformation nephogram of the RV reducer cycloid-pin wheel as shown in Figure 2, Figure 3 and Figure 4. The maximum contact stress between cycloid wheel and pin is 166.22 MPa according to the contact stress nephogram and each cycloidal gear only has half area existing contact stress. The maximum equivalent stress is 279.48 MPa between cycloidal gear and pin, which is bigger than the contact stress of 113.26 MPa. It shows that the cycloidal-pin wheel mechanism loads the main driving force. The contact stress and internal stress all have important influence to cycloidal-pin wheel mechanism. The maximum contact stress and equivalent stress of cycloidal-pin wheel mechanism is far less than the yield limit. So the strength is enough. The maximum deformation of cycloid gear is 0.0365 mm according to Fig.4, while the deformation of pin is approximate to zero. It is mainly due to the pin and the pin gear connected through the pin hole and the large stiffness. The deformation is not easy to happen when it would be loaded.

The contact stress, equivalent stress and deformation calculation results of the eccentric shaft mechanism are shown as Figure5-7 respectively. The maximum contact stress of the RV reducer eccentric shaft mechanism is 113.99 MPa and the maximum equivalent stress is 51.46 MPa. The contact stress is bigger than the equivalent stress, meaning the eccentric shaft mechanism is mainly composed of contact stress. Both the maximum contact stress and the maximum equivalent stress of the eccentric shaft mechanism are far less than the yield strength. So the strength is enough. The deformation calculation results of RV reducer eccentric shaft are as shown in Fig.7. The deformation in mechanism is mainly distributed on the eccentric shaft, which is similar to the stress distribution. The maximum deformation is 0.045 mm. The deformation also presents obvious annular, meaning the torsion deformation is the main deformation form of eccentric shaft. The larger deformation areas are mainly distributed on the two eccentric shaft sections. Under the condition of rated load, the eccentric shaft deformation is larger. It will be one of the main factors affecting the whole transmission stiffness.

![Figure 2](image2.png)  ![Figure 3](image3.png)  ![Figure 4](image4.png)

Figure 2 The contact stress nephogram of cycloid-pin wheel
Figure 3 The equivalent stress nephogram of cycloid-pin wheel
Figure 4 The equivalent deformation nephogram of cycloid-pin wheel

![Fig.5](image5.png)

Fig.5 The contact stress nephogram of eccentric shaft mechanism

![Fig.6](image6.png)

(a) The equivalent stress nephogram of eccentric shaft
(b) The equivalent stress nephogram of eccentric shaft bearing

Fig.6 The equivalent stress calculation results of eccentric shaft mechanism
2.3 The analysis of calculation results
The finite element calculation results show that the cycloidal-pin wheel mechanism transmit the main force. The stress status of eccentric shaft and eccentric bearing mechanism is mainly contact stress. The internal stress of components is smaller and far less than the corresponding material strength. It suggests that the strength is not the main consideration of the RV reducer components in design and manufacture. In order to ensure the accuracy in the process of the RV reducer running, stiffness of the components is the key problem in the process of design and manufacture. The above calculation results show that the deformation of cycloidal-pin wheel mechanism is less than that of the eccentric shaft mechanism. In order to ensure the transmission precision of the reducer machine, the stiffness of eccentric shaft mechanism should be ensure firstly in the process of design and manufacture. The deformation of the eccentric shaft and cycloid-pin wheel are roughly along the radial direction from inside to outside increasing gradually. In the process of manufacture, the materials and manufacture processes of the eccentric shaft should be rational chosen to improve its stiffness. In the process of the cycloid gear tooth profile modification, the reasonable modification method and modification should be chosen.

3. Conclusion
In this paper, the finite element method were used to analyze the key structures of the RV reducer, such as the cycloidal-pin wheel mechanism and the eccentric shaft mechanism. The results are shown as follow:
(1) The stress status of cycloidal-pin wheel mechanism is mainly equivalent stress, while that of the eccentric shaft mechanism is mainly contact stress. The internal stress of the components is smaller and far less than the corresponding material strength. It suggests that the strength is not the consideration of RV reducer components in design and manufacture.
(2) The stiffness of eccentric shaft is smaller than the cycloidal-pin wheel, which has a great influence on the transmission accuracy of the whole machine. Therefore, the materials and manufacturing processes should be reasonable selected to improve its stiffness. As for the cycloid gear, it needs to choose the modification methods and modification according to the deformation reasonably so as to improve its rigidity. Finally, the transmission accuracy of reducer will be improved.

4. References
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