Simulation and analysis of contact state between cycloid gear and pin wheels in RV reducer

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Abstract. By using the finite element method, the contact state between cycloid gear and pin wheels of RV reducer is simulated and analyzed. The comparative analysis about the number of contact teeth pairs between cycloid gear and pin wheels, and the maximum values of contact stress under different working loads (output torques) is completed. The results show that the dowel pin hole on cycloid gear has a certain extent influence on the contact state between cycloid gear and pin wheels. With the increase of working load of RV reducer, the deformation quantity of dowel pin hole on cycloid gear also increasing, it makes the number of the contact teeth pairs between cycloid gear and the pin wheels increasing at the same time. Therefore, the deformation of dowel pin hole is beneficial to improve the contact state between cycloid gear and pin wheels.

1. Introduction

RV reducer is a new type cycloid transmission reducer, which is developed on basis of traditional cycloid needle wheel planetary reducer. It has the advantages of large transmission ratio, compact structure, high motion precision, large stiffness, small hysterisis error and high transmission efficiency [1]. And it is widely used in field of industrial robots, engineering machinery, aeronautics and astronautics [2, 3]. The mechanism kinematic diagram of RV reducer as shown in figure 1, the reducer is composed of involute cylindrical gear transmission mechanism (the first stage) and cycloid needle wheel planetary transmission mechanism (the second stage) [4]. It mainly includes seven kinds of parts, which are sun gear, planetary gear, crank shaft, pin wheel, cycloid gear, planet carrier and pin wheel housing [5]. Among them, the cycloid needle wheel planetary transmission is realized by the meshing of the cycloid gear and pin wheels.

Scholars have researched the effect of radial and pin-hole clearances, as well as eccentricity errors on some key design factors of cycloid speed reducer [6]. In addition, the lost motion of a cycloid reducer has been investigated through combining FE and kinematic analyses [7]. However, the influence of cycloid gear structure on contact state between cycloid gear and pin wheels in RV reducer has not been studied yet. Therefore, this paper makes a specific study on this problem.

Because of the complex load condition in actual working process of the RV reducer, it is difficult to accurately analyze the contact state between cycloid gear and pin wheels through the traditional theory. Therefore, finite element method is used to study the influence of different working load values on the contact state between cycloid gear and pin wheels in RV reducer. And then, the reasons are analyzed. It is expected to provide reference for the design and related research about cycloid gear of the RV reducer.
2. The establishment of finite element model used for simulation

The model used for simulation analysis is the assembly body of the cycloid gear and pin wheels of RV reducer. (As shown in figure 2, for easy explanation, the number of the cycloid teeth is marked from 1 to 39.) It includes a cycloid gear and 40 pin wheels. Then, the finite element meshes of gear teeth and gear body of cycloid gear are divided. And the meshes are divided by tetrahedral elements and hexahedral elements in the wheel and tooth parts, respectively. The finite element model of the cycloid gear is obtained as shown in figure 3, which consists of 62799 elements and 234384 nodes.

The RV reducer for studying adopts the working mode that the planet carrier is fixed and pin wheel housing is output. On this basis, the load and constraint conditions of the simulation model are determined. 40 pin wheels are fixed. And cylindrical constraint is imposed on input shaft hole of cycloid gear, which the circumferential direction is free, and the radial and axial directions are fixed. Finally, the total load is applied to the three bearing holes averagely in the form of forces. And the directions of the forces are shown by $F$ in figure 2. (The arm of force $F$ is 42mm.)

3. Finite element simulation and analysis

Through refer to the literature [8], the values of output torque of the RV reducer are given. And the load values required to be applied to the position of crank shaft hole are calculated, as shown in table 1.

![Figure 1. The mechanism kinematic diagram of RV reducer.](image1)

![Figure 2. Schematic diagram of assembly model used for simulation and analysis.](image2)

![Figure 3. The finite element model of cycloid gear of RV reducer.](image3)
Table 1. The load value of finite element simulation.

| The output torque of RV reducer T/(N•m) | 584 | 672 | 784 | 885 | 988 | 1088 | 1188 |
|----------------------------------------|-----|-----|-----|-----|-----|------|------|
| The load of per crank shaft hole F/N    | 2434| 2800| 3267| 3688| 4117| 4534 | 4950 |

By applying the load values in table 1 to the finite element model, the maximum contact stress and the number of the meshing teeth pairs between the cycloid gear and pin wheels are obtained by finite element simulation (as shown in table 2). The simulation results show that the maximum stress appears at No. 4 tooth. The stress nephogram and deformation nephogram of cycloid gear under the torque value of 1088N•m are shown as figure 4 and figure 5, respectively. When the output torque is other values, the deformation trend is the same as this.

Table 2. The contact state obtained by finite element simulation.

| The output torque of RV reducer T/(N•m) | The number of teeth pairs subjected load | The serial number of teeth pairs subjected load | The maximum contact stress/MPa |
|----------------------------------------|----------------------------------------|-----------------------------------------------|-------------------------------|
| 584                                    | 4                                      | 1,2,4,11                                      | 302                          |
| 672                                    | 6                                      | 1,2,3,4,5,11                                  | 333                          |
| 784                                    | 6                                      | 1,2,3,4,5,11                                  | 362                          |
| 885                                    | 8                                      | 1,2,3,4,5,10,11,12                            | 381                          |
| 988                                    | 8                                      | 1,2,3,4,5,10,11,12                            | 399                          |
| 1088                                   | 8                                      | 1,2,3,4,5,10,11,12                            | 412                          |
| 1188                                   | 8                                      | 1,2,3,4,5,10,11,12                            | 429                          |

It is known from data of table 2, with the increase of the working load (output torque) of the RV reducer, the number of contact teeth pairs between cycloid gear and pin wheels also increases gradually.

![Figure 4. The stress nephogram of cycloid gear.](image1)

![Figure 5. The deformation nephogram of cycloid gear.](image2)

In addition, as shown in figure 6, by observing the variation trend of the maximum contact stress following the output torque, the phenomenon that with the increase of working load, the increasing trend of the maximum contact stress gradually slows down can be found. The slope has a gradually decreasing trend with the output torque increase. This phenomenon is because, as the increase of load, the elastic deformation of the dowel pin hole near the No. 11 tooth is increasing, resulting that No. 10
tooth and No. 12 tooth near the No. 11 tooth also meshed with the corresponding pin wheel. Furthermore, the increasing of contact teeth pairs number is helpful to slow down the growth rate of maximum contact stress.

Therefore, the elastic deformation of dowel pin hole on the cycloid gear of RV reducer is helpful to improve the contact state between the cycloid gear and pin wheels. With the load increasing, the number of teeth pairs can be also increased. It is beneficial to improve the carrying capacity of meshing between cycloid gear and pin wheels.

4. Conclusions
In this paper, the finite element simulation of assembly consist of cycloid gear and pin wheels of RV reducer is completed, which adopts the working mode of fixing the planet carrier and the output is pin wheel housing. The following conclusions are obtained by comparing the contact conditions under different loads.

(1) With the increase of the working load (output torque) of the RV reducer, due to the elastic deformation of dowel pin hole on cycloid gear, the number of contact teeth pairs between cycloid gear and pin wheels increases gradually;

(2) With the increase of the working load (output torque) of the RV reducer, due to the number of contact teeth pairs between cycloid gear and pin wheels increases, the growth rate of maximum contact stress gradually decreases.

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