Structure design and motion simulation of the pin-cycloid gear planetary reducer with ring-plate-type

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Abstract. The pin-cycloid gear planetary reducer with ring-plate-type is a new type of reducers. It has high transmission ratio range and high efficiency. In this paper the working principle of pin-cycloid gear planetary reducer is discussed, and the structure of the reducer is designed. Especially for the complexity and the difficulty in modelling of the cycloid gear tooth profile, the parametric design module of cycloid gear is developed to solve the cycloid gear modelling problem through the second development of Solid Works. At last, the speed schemes of the input shaft and output shaft of the reducer are obtained by the motion simulation. Through the analysis of the simulation curves, the rationality of the structure design is proved, which provides a theoretical basis for the design and manufacture of the reducer.

1. Introduction
The ring-plate-type pin-cycloid gear planetary reducer is a new type of reducer integrating the advantages of the ring plate gear transmission and the traditional cycloid planetary gear drive. It has large transmission ratio range, high transmission efficiency and smooth transmission. In addition, because it moves the rotary arm bearing of the cycloid pin wheel planetary transmission to the outside of the planet wheel, the size is not limited, which eliminates the complex output mechanism of cycloid pin wheel planetary transmission. Accordingly, it has larger output shaft rigidity and bearing capacity, which makes it to be widely used in heavy industry, such as petroleum, chemicalmining and other heavy industries [1][2]. It is a new type of speed reducer with great research and development value.

The motion simulation of the pin-cycloid gear planetary reducer with ring-plate-type can be used to virtual reducer structure and transmission, help designers to optimize the structure design through changing the motion parameters and judge whether the structural design of the reducer meets the requirements in the early design stage, thus saving the trial cost and shortening the product development cycle.

2. Structure design of the pin-cycloid gear planetary reducer with ring-plate-type

2.1. Working principle of reducer
The working principle of ring plate type cycloid reducer with double crank is shown in Figure 1 [3,4]. On the connecting rod BC of the parallel four-bar mechanism ABCD, a pin wheel 2 is provided, and its centre $O_p$ is located at the midpoint of the connecting rod BC. The cycloid wheel 5 is meshed with the pin wheel 2, and the centre $O_2$ of wheel 2 is located at the midpoint of the A and D connections, where, A and D are the rotary centres of driving crank AB and driven crank CD, respectively.
Furthermore, the length of the driving and driven crank is equal to the centre distance of the wheel and cycloid. In the parallel four-bar mechanism ABCD, because the connecting rod makes a translational, all of the points on the connecting rod have the same movement trajectory, velocity and acceleration. Therefore, the trajectories of the needle wheel centre $O_p$ fixed to the connecting rod BC must be a circle with radius e and centre $O_c$.

![Diagram](image)

1 Active crank; 2 Pin wheel (ring plate); 3 Driven crank; 4 Machine frame; 5 Cycloid wheels

**Figure 1.** The ring-plate-type pin cycloid gear planetary reducer diagram of mechanism

If the pitch circle radius of the cycloid wheel and pin wheel are $R_e$ and $R_p$, then the centre distance is $E = R_p - R_e$ if the angular velocity of the driving crank is $\omega_1$, then the linear speed at B is $V_b = \omega_1 E$, its direction is perpendicular to the driving crank AB, and its pointer is consistent with the turning direction of $\omega_1$. Because the velocity direction $v$ and $V_b$ of the cycloid wheel is same as pin wheel meshing point P, the rotation direction of cycloid wheel around $O_c$ is opposite to the rotation direction of driving crank around A, that is to say if the direction of $\omega_1$ is count clockwise, then $\omega_2$ must turn clockwise.

The reducer transmission ratio of double crank ring plate type pin-cycloid planetary is:

$$I_{12} = \frac{\omega_1}{\omega_2} = \frac{Z_p}{Z_p - Z_e}$$

Where, $Z_p$ is the teeth number of the pin wheel, and $Z_e$ is the teeth number of the cycloid.

### 2.2 Structure design of reducer

The reducer has a horizontal installation and a horizontally split structure, and is composed of a box body, two input shafts and an output shaft, as shown in Figure 2. Two input shafts with four eccentric wheels respectively connected the four inter gear ring plate with pin wheel together, which forms four sets of parallelogram mechanisms. The input shaft (high speed shaft) drives the four ring plates for the plane movement through the eccentric wheel, and the pin tooth of the inner ring plate meshes with the cycloid wheel, so as to toggle the cycloid wheel rotation to drive the output shaft output motion. In the four sets of parallelogram mechanism, the two groups of the middle have the same phase angle, and the two structures in the two sides have the same phase angle. The difference phase angle between the two groups in the middle and the two groups in the sides is 180 degrees.
1 input shaft 2 eccentric sleeve 3 cycloid wheel
4 output shaft 5 ring plate 6 input shaft b

**Figure 2.** The pin-cycloid gear planetary reducer with ring-plate-type

### 2.3 Parametric design of cycloid gear

The cycloid gear tooth profile is an important geometric factor for the transmission efficiency and transmission quality of reducer, so the design of the cycloid gear tooth profile is the key part in the reducer structural design. The tooth profile curve of the cycloid gear is very complicated, and SolidWorks software does not have the function of generating the free curve. Therefore, it is necessary to make the secondary development of Solid Works in the integrated development environment of Visual C++ 6.0, and increases the cycloid gear parametric design module to lay the foundation for the overall design modelling of reducer.

In order to facilitate the assembly and disassembly of pin cycloid planetary reducer, and compensate the thermal expansion and the manufacturing error caused by the temperature rise, in the parametric design of cycloid gear, the cycloid equation of tooth profile must be modified [5]. The equation is shown as:

\[
X_c = \left( R_p - \Delta R_p \right) \sin \left( (H - 1) \varphi + \delta \right) \\
- \left( A + \Delta A \right) \sin \left( f^H \varphi + \delta \right) \\
+ \left( R_p + \Delta R_p \right) K_1 \Delta \sin \varphi
\]

\[
Y_c = \left( R_p - \Delta R_p \right) \cos \left( (H - 1) \varphi + \delta \right) \\
- \left( A + \Delta A \right) \cos \left( f^H \varphi + \delta \right) \\
+ \left( R_p + \Delta R_p \right) K_1 \Delta \cos \varphi
\]

Where: 

\[ K_1 = \frac{Z_p (A + \Delta A)}{(R_p - \Delta R_p)} \]

\[ X_c \] and \[ Y_c \] correspond to the x-axis, y-axis coordinate’s value of the point on the cycloid curve, respectively.

Through the OLE technology, SolidWorks provides a powerful second development interface API for users [6]. Using the COM technology, we writes the dynamic link library DLL files (plug-in) based on COM with VC, so as to load the plug-indirectly add the design menu of cycloid wheel parameters in the Solid Works menu bar, which realizes the seamless integration with Solid Works. The parameterized design interface of cycloid wheel can be obtained by clicking the parameterized design menu.

Calculate \( x, y \) coordinates of each points on the cycloid gear tooth profile curve by using VC program [7]. Using the function `odelDoc2->Sketch Spline(more Pts, x, y, z)`, a series of points are used to synthesize the cycloid tooth profile curve through point's coordinates. After the cycloid wheel tooth profile curve generated, the three-dimensional model of the cycloid wheel will be established by
creating stretching characteristic function basing on sketches entity conversion function. The parametric design interface of the cycloid wheel is shown in Figure 3.

![Parametric design interface and the three-dimensional model of cycloid gear](image)

**Figure 3.** Parametric design interface and the three-dimensional model of cycloid gear

### 3. Motion simulations

The pin-cycloid wheel planetary reducer's transmission mode is cycloid pin gear transmission, and the meshing mode between the pin gear sleeve and the cycloid wheel is the tooth profile's meshing. Through the contact between the pin gear sleeve and the cycloid wheel, the cycloid wheel is rotated, thus the output motion is achieved. The motion simulation of the ring-plate-type pin cycloid planetary reducer determines the kinematic relationship between the parts by defining the kinematic pairs between the various parts of the reducer; That the loading rotating motor works on the input shaft achieves a definite movement of the moving parts in the reducer; adding to contact between the pin gear and the cycloid prevents the parts mutual penetration [8]. Then it will have the collision force between the pin gear and the cycloid to drive cycloid wheel rotation. Speed, acceleration and displacement at the motion position of any points of the graphic curve can be obtained. Through the analysis of these graphic curves, it can judge whether the structure design is reasonable and provide the basis for the optimal design.

The rotational speed of set rotary motor is 1500r/min; the motion of the planetary reducer is simulated. The simulation results of ring plate velocity and displacement diagram are shown in Figure 4, Figure 5.

From Figure 4, the curves of the linear velocity X and Y axis component of the ring plate changing with time are sine curve, and the cycles are all 0.04s, which matches with the expected design. The design speed of the ring plate is 314mm/s; the ring plate linear velocity X axis component is 303mm/s; Y axis component is 314mm/s; the overall speed is 314.2mm/s. It can be seen that the ring plate linear velocity Y axis component and amplitude are consistent with design speed perfectly, while the X axis component has a slight error. Through the graphic of the ring plate linear velocity X axis component, it can be seen that the highest point and the lowest point of the curve is not particular smooth, while the location of the two points happened to be the dead point position of mechanism. Thus, when passing the dead point position, the ring plate has a certain resistance with the speed decreased slightly; the volatility is relatively small, which has a little impact on the overall speed and can meet the design requirements.
Figure 4. The ring plate linear velocity diagram

From Figure 5, the curves of the linear displacement X and Y axis component of the ring plate changing with time are all standard sine curves. It can be obtained from the abscissa of the diagram that the cycle of the sine curve is 0.04s; the rotary speed of the input shaft of the motor is 1500 rev/min; the rotary cycle of the input shaft is 0.04s; the diagram is in accordance with the design expectation. It can be seen from the ordinate of the diagram that the amplitude of the sine curve is 2mm, that is, the maximum displacement of the ring plate in the X and Y axis is 2mm, while the design eccentricity is 2mm. Therefore, the ring plate track is the same as expected.

Figure 5. The ring plate linear displacement diagram
The simulation results of the input shaft and the output shaft speed are shown in Figure 6.

![Graph showing simulation results](image)

**Figure 6.** The input shaft and the output shaft angular velocity

It can be seen from Figure 6, when the motor starts, the speed of the input shaft increases rapidly to 15000 deg/sec, and then it quickly drops to 9000 deg/sec. At last, it is stable in 9000 deg/sec. The reason for this phenomenon is that reducer model of each moving parts has the gap, so motor starting moment has no-load instantantly, which causes the speed fluctuation. Finally, the input shaft speed stabilizes in 9000 deg/sec (1500 r/min), which is consistent with design speed.

Furthermore, from Figure 6, it can be seen, just at the start, the angular speed fluctuation of reducer output shaft is relatively large, then it stabilize in the vicinity of 818 deg/sec, that fluctuates from 780 deg/sec to 850 deg/sec, that is, the fluctuation is in the 136 r/min. It is very close to the theoretical design of the output shaft design angular velocity of 818 deg/sec, or 136 r/min. In the simulation process, the angular velocity of output shaft has a slight fluctuations and error, which probably caused by a parallel mechanism through two dead centre operation unstable, it has the impact on the output shaft angular velocity; and it also caused by the friction and collision between reducer parts, especially between the pin gear sleeve and cycloid wheel. At the same time, it also illustrates that the cycloid wheel tooth profile modification is not ideal and need to further optimize.

4. Conclusions

The results of the reducer’s motion simulation are in good agreement with the design expectation, and the motion simulation of the reducer provides the necessary guidance for the structural optimization design of the ring-plate-type pin-cycloid planetary reducer. The cycloid profile can be further optimized to determine the appropriate modification parameters and modification methods of profile. If we test the vibration of the reducer’s different operating conditions by using integration multi acoustic vibration analysis system, and analyze the vibration effect among the teeth and the influence of geometric parameters on the gear system dynamics, an optimized design scheme will be reached.

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