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Finite Element Dynamic Simulation and Fatigue Life Test Analysis of RV Reducer

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Abstract: *Objective: To study the fatigue life test of RV reducer. Methods Using Solid Work software based on finite element method, 3D modeling of RV reducer related parts was conducted, and fatigue life test analysis was conducted.Results By constructing a finite element analysis model, the fatigue test of the RV reducer, and the corresponding safety factor is more concentrated on the bearing, and the safety factor between the wheel and more than 15, the experiment further verifies the effectiveness of the method to test the qualification of the reducer.*

Keywords: *RV Reducer; Finite Element Model; Finite Element Dynamic Simulation; Fatigue Life*

1. Introduction

The structural equipment composed of metal, plastic, concrete and other materials will have material fatigue problems under the long-term effect of special loads. The fatigue damage phenomenon caused by fatigue widely exists in most engineering equipment and mechanical structures. Each component of the stressed structure has the risk of fatigue damage. At present, the definition of fatigue failure is: under the action of alternating load, even if the peak stress of the alternating load is lower than the yield limit of the material, the surface of the part will also have crack initiation, propagation and even fracture, which is called fatigue failure. RV reducer is the core component of modern industrial robots, and its fatigue failure is an important problem in the field of industrial robots. The fatigue life of RV reducer is evaluated based on the fatigue analysis of RV reducer and the finite element analysis method in modern drive design, which provides a reference for the safe use of RV reducer.

2. Fatigue damage and failure mode analysis of RV reducer

The fatigue damage of RV reducer parts is mainly concentrated in the contact fatigue failure of cycloidal pin wheel drive of RV reducer. Each time the cycloidal pin wheel drive passes through a tooth, the stress point of contact fatigue failure is affected.[1] Under the continuous effect of this cycle of stress, cracks are generated at the profit point, and eventually the cycloidal gear teeth are contact fatigue shed. Fatigue Failure of RV Reducer Rolling Bearing, RV reducer crank shaft fatigue damage failure,RV reducer rolling bearing bears cyclic stress on crank shaft for a long time, the contact surface of the roller needle is rubbed by metal debris, gluing failure of rolling bearing

3. Establishment of finite element model of RV reducer

In this study, the finite element model was established using SolidWorks software, and each component of the RV reducer was modeled in three dimensions. The appropriate component materials were selected in the finite element analysis software Ansys Workbench, and the material properties were called. In order to ensure the accuracy of contact stress simulation results, it is necessary to build the finite element model of RV reducer through the finite element software ANSYS. The corresponding cycloidal gear teeth are in the tooth contact position. In order to carry out the fatigue contact research orderly, it is necessary to further refine the finite element mesh division of cycloidal gear teeth, as shown on the left in Figure 1 below.[2] The corresponding spokes, needle gear shells and other parts that are far away from the meshing area have little impact on the results. Sparse grids can be used to divide and replace them to promote the effective saving of computer resources. For the planet carrier of RV reducer, it can be connected through the truss mode of rigid beam element to build the model of planet carrier and release the rotational freedom of the end node of rigid beam element to simulate the rotating arm bearing of the planet carrier. The discontinuous grids with different density characteristics are connected by coupling and constraint equations, and then the corresponding parts of the reducer are assembled, so a finite element model of cycloidal pin wheel drive of RV reducer is built.

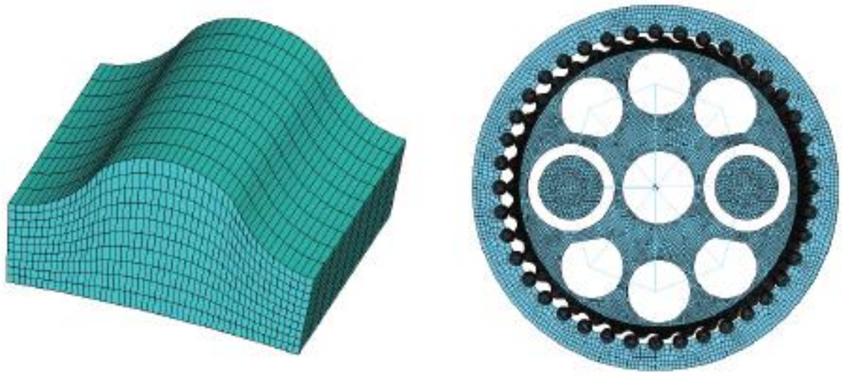

Figure 1: Finite element model of cycloidal gear (left) Finite element model of cycloidal pin gear transmission (right)

In order to ensure the dynamic process of the cycloidal gear rotating relative to the crank shaft, it is necessary to remove the wall bearing of the cycloidal gear bearing hole, and simulate the rotating motion of the bearing through the type of constraint elements in the finite element software. A single node is generated at the center of the cycloidal bearing hole, and then the nodes on the inner surface of the cycloidal bearing hole are selected. The multi-point constraint equation is automatically generated between the nodes on the center of the bearing hole and the nodes on the inner surface of the bearing hole. At the same time, multi-point constraint equations are automatically generated between the crank center and the surfaces in the crank shaft area. In addition, by means of hinge, a rotation pair unit is established along the Z axis at the center of the cycloidal bearing hole and the crank shaft area.[3]

4. Calculation of maximum contact stress

Considering that the RV reducer is affected by many factors in all aspects during its travel, including climate, road conditions and vehicle movement status, it is difficult to accurately calculate the stress on the corresponding parts of the reducer when the RV reducer is traveling. In carrying out the force analysis of the reducer as a whole, first make samples, and then carry out stress and strain analysis. The application of relevant methods requires more investment. The vehicle driving test and bench test for the reducer sample is one of the usual methods for checking the strength and stiffness of the reducer in China. To collect the reducer stress of RV reducer, you can also use the electrical measurement method of sticking strain gauges on the reducer, so that the car can run with full load on the selected typical road section. Isuzu Corporation of Japan has developed a new calculation method, that is, stress deformation calculation is carried out through elasticity, and the reducer geometry is simplified with the help of relevant analysis results. This analysis method has a certain accuracy, but the calculation results are affected by many limiting factors. Generally speaking, in the design of the reducer, the conventional design method can be selected to take the reducer as a simply supported beam and check the maximum stress value of its specific section. A Japanese company has designed the reducer to ensure that the corresponding section stress does not exceed the yield limit under the action of 2.5 times the axle load under full load. In combination with the automobile production and manufacturing situation in China, the complex force situation of the reducer can be simplified into three typical working conditions during the calculation, and the complex force situation of the reducer during vehicle driving can be taken into account, and the vertical force, tangential force, traction force, braking force, etc. can be comprehensively considered. The force that affects the drive reducer is ignored and the calculation process is simplified.

As shown in Figure 2 below, it is the basic structure of RV reducer:

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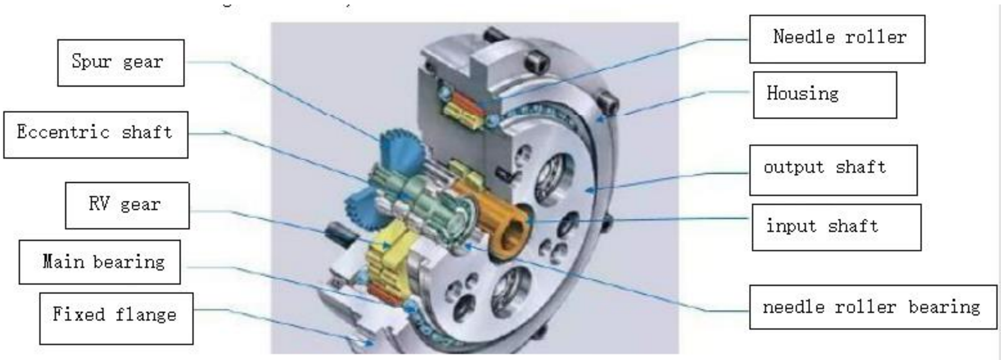

Figure 2: Basic Structure of RV Reducer

According to the structure of RV reducer, its main components include spur gear, eccentric shaft, RV gear, main bearing, fixed flange, needle roller, housing, output shaft and needle roller bearing. For this, these components can be analyzed as a whole as a finite element analysis. At present, most of the relevant components of the RV reducer are made of cast steel, and the half shaft sleeve is generally made of ultra-high strength steel. The material performance of the relevant departments can be seen in the production standards of the RV reducer. After the axle shaft sleeve and housing are integrated, the RBE2 unit is used to connect the reducer body and axle shaft sleeve with given constraints and loads. Then, the two half shaft bushings are constrained respectively. The uppermost part of the center interface of the reducer body is constrained to move along the x-axis. The contact area between the shaft sleeves at both ends of the reducer and the hub bearing is constrained to move along the y-axis and z-axis from the node and rotate around the y-axis and z-axis. Apply the load under the maximum vertical force to the leaf spring seat. When the RV reducer is running on a bad road, the random dynamic load it needs to bear is 2.5 times more than its static full load axle load, and the vertical impact load is about 162.5 mn. Solve the relevant nodes where the vertical force is evenly applied to the spring seat to obtain the static condition of finite element. The experiment found that the overall maximum stress value of RV reducer under the maximum vertical force condition is about 1107.343MPa. In this way, the maximum stress value of RV reducer is much smaller than the yield strength of its material. Therefore, it is concluded that under the maximum vertical force, the safety margin of the drive reducer of RV reducer is sufficient. However, there is some deviation between this calculation result and the finite element calculation and analysis result. This is because there is a certain change between the contact state caused by the elastic deformation of the spoke and the actual number of teeth engaged, which affects the finite element calculation result. However, the theoretical contact stress is assumed to be rigid, so there may be some deviations in the results.

5. Contact fatigue failure mechanism and fatigue strength design of cycloidal pin wheel drive of RV reducer

5.1 Contact fatigue failure mechanism of cycloidal pin gear transmission

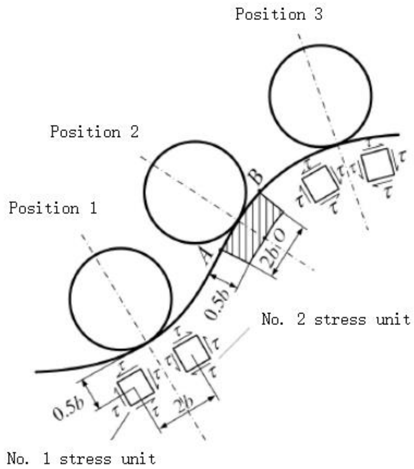

Figure 3: Contact Fatigue Failure Principle

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Combined with the dynamic meshing process of cycloidal needle gear drive, the needle gear moves along the cycloidal tooth profile at the unknown starting point. In the case of contact between two cylinders whose axes are parallel to each other, on the plane 0.5b below the contact surface, the corresponding contact area width is 0.85b E-commerce. When the shear stress is maximum, the needle tooth moves to point A. At this time, No. 2 stress unit moves to point O. The shear stress direction is positive. When the gear runs to point B, No. 1 stress unit reaches point O at this time, and the direction of shear stress is negative. As a result, when the cycloidal needle wheel drive rotates one tooth each time, there will be a shear stress cycle at point O below position 2. Therefore, the stress source of contact fatigue failure of cycloidal pin gear drive is the symmetrical cyclic shear stress at the O point. Under the influence of such cyclic stress, the O point cracks also develop around the O point and expand the contact surface with the increasing number of cycles. Finally, the cycloidal gear falls off due to contact fatigue. See Figure 3 below for details:

5.2 Design of contact fatigue strength of cycloidal pin gear transmission

The calculation of contact fatigue strength can predict the contact fatigue life. This calculation is based on the S-N curve, but there is a certain difference between the S-N curve from contact and the tensile bending fatigue curve. The ordinate of this curve represents the maximum contact stress. The curve is mainly obtained through the contact fatigue test. In combination with the difference of test loading conditions, the stress concentration and the stress after local plastic deformation are not redistributed, Different maximum contact stresses can be obtained by combining Hertz's theoretical formula. Under the maximum contact stress, it is necessary to carry out the test to obtain the corresponding number of stress cycles, and finally obtain the contact fatigue curve through statistics. For the white wire needle wheel drive of RV reducer, the cycloidal gear surface will be subject to the maximum stress every time the crank shaft rotates for one circle, so relieving the load from fart is equal amplitude pulsation cycle. The corresponding stress amplitude is 847.87APa. To calculate the contact fatigue life of cycloidal gears, it is necessary to master their fatigue strength and the relationship between the external contact stress and the number of stress cycles.

According to the experiment, the rated output speed of RV reducer needle gear housing is 15r/min, and the rated speed of crank shaft is 600r/min based on the reduction ratio of crank shaft and needle gear housing In this way, the stress cycle will occur once every time the crank shaft rotates, so that the number of stress cycles for cycloidal gear fatigue failure can reach N=4.0448 × 1011 times. So the fatigue life value of RB reducer is T=1.1247 × 107 hours. From this value, the fatigue life prediction of the reducer is close to the wireless fatigue life, and the product meets the quality requirements.

6. Conclusion

RV reducer is mainly composed of box, worm gear, worm, bearing, input shaft, output shaft and some small accessories (see the above figure). Due to the worm gear structure, the reducer has low noise and large output torque, and is suitable for various working conditions. As for its working principle, the motor of the reducer is connected with the flange and transmitted to the worm gear through the worm. Worm and worm gear can produce various speed ratios, which can reach 1/100 in common use. If a higher speed ratio is required, two sets can be used in series. The output shaft is installed in the inner hole of the worm gear and can be used as a conventional shaft, spline shaft or output hole. It is flexible. Combined with the analysis, the fatigue test of RV reducer was carried out by building a finite element analysis model. It was concluded that there was no contact fatigue damage in the cycloidal gear and pin gear engagement. The parts with lower safety factors were more concentrated in the cycloidal gear bearing. The safety factor of the gear engagement position between the cycloidal gear and pin gear exceeded 15. The experiment further verified the effectiveness of the method. Through the application of this analysis method, it can check whether the design and manufacturing of relevant reducer products are qualified, and provide a basis for ensuring the safe and effective operation of vehicles.

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