Dynamic and Finite Element Analysis of Double Cylindrical Gears Based on CAE

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Abstract: *The kinematics simulation of double circular arc gear is carried out, and the angular velocity and acceleration curves of the main and driven wheels are obtained. The finite element analysis of the gear is carried out, including the modal analysis of the gear and the contact analysis of the tooth surface. The analysis shows that the designed gear meets the design requirements, so as to ensure the accuracy of the gear design.*

Keywords: *CAE; gear; stress; dynamics; FEA*

I. Introduction

The circular arc gear is the third most commonly used tooth shape after cycloid and involute. It differs greatly from cycloid and involute gears. When the helix angle is small, the contact line and tooth width of cycloid and involute teeth are parallel. The relative curvature radius which determines fatigue strength can only be increased by increasing the diameter of gear. The contact line of circular arc gear is nearly parallel to the tooth height, and the relative curvature radius of fatigue strength can be increased by reducing the helix angle. In this way, when the same diameter gear is used, the fatigue strength of circular arc gear will be greatly improved, so the same requirement can be fulfilled with softer materials. The concave and convex teeth of circular arc gears are a pair of cylindrical surfaces rubbed on the axial normal surface at the moment of contact. They are very easy to run in. Therefore, if the accuracy of circular arc gear does not occur gluing, sometimes it will improve with the use, or at least reduce slowly. In other words, the running-in performance of circular arc gears is better.

With the development of production, higher requirements are put forward for heavy-duty, high-speed and high-power gears. Because the transmission of involute gears with external engagement is convex profile to convex profile, in order to reduce the contact stress, the curvature radius of the tooth surface must be increased, and the diameter of the gears must be enlarged, so it is difficult to meet the requirement of small volume. Moreover, the transmission efficiency of involute gears is not high enough, which causes great difficulties in heat dissipation of compact high-power and high-efficiency transmission. Through dynamics and finite element simulation, the efficiency of gear optimization design can be effectively improved.

II. Meshing Characteristics of Circular Arc Gears

2.1. Single circular arc gear

The working tooth profile of a single circular arc gear has only one arc and only one contact point. The axial distance between the two adjacent teeth is the axial distance. The minimum contact point of a single circular arc gear is equal to the integral part of the coincidence degree. Joint back meshing is more advantageous to the formation of oil film dynamic lubrication between tooth surfaces, and the bearing capacity of tooth surfaces is stronger. Therefore, single circular arc gears usually make the driving wheel into cam teeth. In deceleration drive, the pinion is the driving wheel, which is made into convex teeth, which is also beneficial to the strength of the gear shaft. A pair of intermeshing single circular arc gears, the pinion is made into a convex profile. The convex profile is located outside the pitch circle, and the large gear is made into concave profile. The concave tooth profile is located in the pitch circle, which can avoid interference between the tooth profiles. There is no undercutting restriction for circular arc gears, and the number of pinion teeth can be very small, but too few teeth is not easy to ensure sufficient longitudinal coincidence. In addition, the strength and stiffness of the gear shaft will be affected. Therefore, making the pinion profile outside the pitch is beneficial to the strength and stiffness of the shaft.

2.2. Double circular arc gear

The working tooth profile of double circular arc gear is composed of two segments of arc, that is, the convex tooth profile outside the indexing circle and the concave tooth profile within the indexing circle have one contact point, so it has both the back meshing of the nodes and the front meshing of the nodes. The tooth surface of circular arc gear is the envelope surface of the basic rack tooth surface in relative motion. The tooth surface equation of circular arc gear is established by taking the basic tooth profile of circular arc gear as the normal section tooth profile of the basic rack. Double circular arc gear is a single circular arc gear's convex teeth and concave teeth are made on single gear teeth, outside the pitch circle is the convex tooth profile, within the pitch circle is the concave tooth profile. In meshing, there are two meshing lines. In front of the nodes, the concave tooth profile of the driving wheel drives the cam tooth profile of the driven wheel.

III. Kinematics simulation of double circular arc gear

3.1. Establishment of model

The three-dimensional model of double circular arc gear pair is imported into ADAMS software, and constraint fit is added. As shown in Fig.1, the main constraints are as follows: the rack and ground are fixed constraints, the rotating pair is added between the rotating center of the driving wheel and the rack, the gear matching is added between the two double circular arc gears, and the driving wheel is applied to power, so that the speed of the motor is v=50r/min.

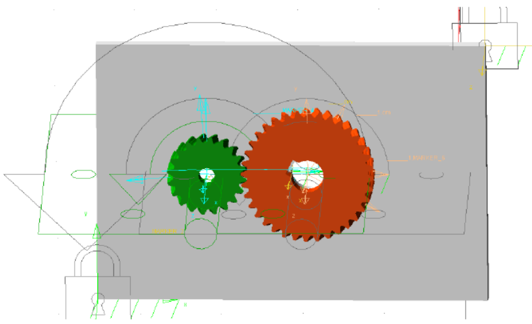


Fig.1 Double circular arc gear pair

3.2. Result analysis

The final angular velocity curves of the main and driven gears are shown in Figs.2 and Fig.3. It can be seen from the figure that the angular velocities of the main and driven wheels change periodically, and the velocities change steadily without major sudden changes.

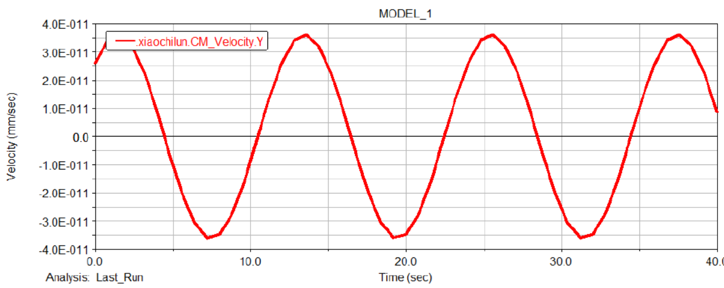


Fig.2 Angular speed curve of double circular arc gear drive wheel

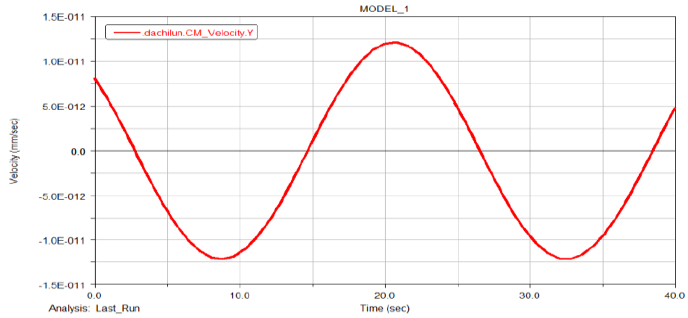


Fig.3 Angular velocity curve of driven wheel of double circular arc gear

IV. Finite element modal analysis of double circular arc gear

4.1. Establishment of model

Vibration is a common problem in gear mechanism. The vibration generated by gears during working will have adverse effects on the working performance of mechanical equipment, thus shortening the service life of double circular arc gears. Therefore, it is necessary to analyze the vibration performance of gears. Modal analysis, also known as free vibration analysis, can be used to study the vibration characteristics of mechanical components. Through modal analysis of double circular arc gear pair, its natural vibration characteristics can be understood, and its natural frequency, damping ratio and mode shape can be studied and analyzed.

The material of double circular arc gear is alloy steel with elastic modulus of E=2.11×10^{11} Pa. The model of double circular arc gear is imported into ANSYS Workbench software and meshed. The size of structure unit is 1 mm. A total of 35982 units and 55651 nodes are generated, as shown in Fig.4

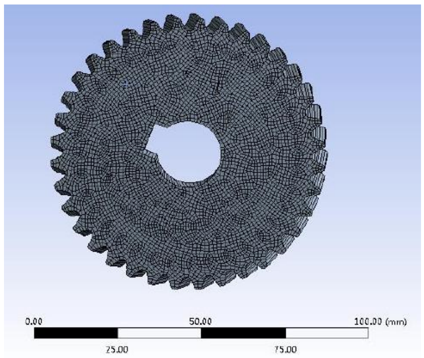
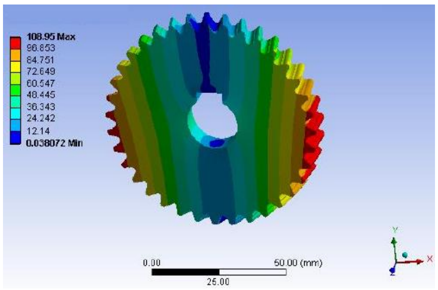


Fig.4 Model diagram of double circular arc gear after meshing

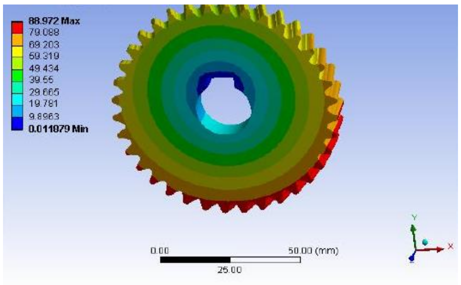
4.2. Result analysis

The boundary conditions of the finite element model of double circular arc gears need to be set according to the actual working conditions. In the meshing process of double circular arc gears, the gears and shafts can be regarded as rigid connections, and the influence of keyway is neglected. Fixed constraints are imposed on the cylindrical surface of the double circular arc gear hole, and the order of extraction frequency is set to 6. The first six modes of the model are obtained by calculating the method. The typical results are shown in Fig.5.

According to the first-order to sixth-order mode shapes of double-circular-arc gears, the deformation of first-order mode gears is very small. With the increase of mode number, double-circular-arc gears have different degrees of deformation. The common point is that the maximum deformation occurs at the top of the gear teeth. In addition, the natural frequency value of the gear is higher, which shows that its dynamic characteristics are better, and it is not easy to occur vibration and impact. At the same time, when the motor rotates at a larger speed, the relationship between frequency and critical speed can be obtained. The actual speed of the gear is far less than the minimum critical speed, so the transmission of the gear meets the requirements of dynamic design.



(a) The third-order



(b) The fourth-order

Fig.5 Mode shapes of double circular-arc gears

V. Contact Strength Analysis of Gear Pairs

5.1. Establishment of model

The contact model is meshed by the idea of meshing in static finite element analysis. After setting the smart size, the mesh divider estimates the edge size of all lines on the surface or body to be meshed, refines the lines of the bending approximation area on the geometric body, and automatically generates the reasonable shape of the unit and the size distribution of the unit. The smart size of mesh generation can be set by basic control and advanced control. The basic control only needs to define the level of mesh size from 1 (fine) to 10 (rough). In the grid partitioning tool, the defined material attributes can be bound to the cell type to partition the grid. The influence of tooth surface curvature on contact stress is significant. The mesh density will directly affect the change of local curvature of tooth surface, and then affect the analysis results. The method of cell mesh generation includes intelligent division and manual assignment of parameters. When intelligent meshing is used, the number of meshes on the tooth surface often falls short of the requirement; higher mesh level will lead to an increase in the number of meshes, and the increase in the number of meshes concerned with the location is not obvious. Manual meshing can produce good results. By setting the number of meshes on the end profile of the meshing tooth surface, the number of meshes along the tooth length, and the number of meshes on the constraint boundary line, the contact tooth surface can have a dense mesh, while the meshes in other non-critical areas are sparse.

The ANSYS finite element mesh model is established, and the global setting is carried out in Mesh Tool. The defined element type, material number, real constant and coordinate system of the element are selected, and then the mesh is divided by SWEEP. The mesh quality is checked and the mesh model is shown in Fig.6. A total of 266860 grids were constructed in this model.

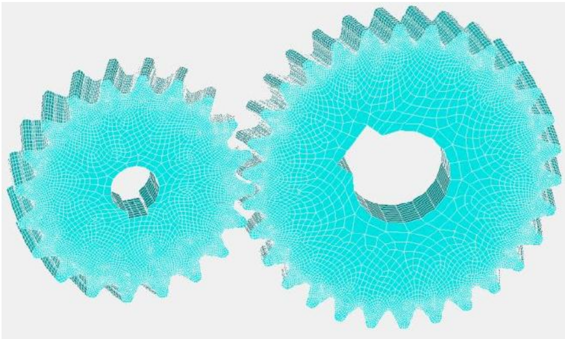


Fig.6 Double circular arc gear model after meshing

5.2. Applying boundary conditions and loading

When element division and boundary conditions are completed, load conditions of gear teeth need to be considered. In this paper, the most disadvantageous situation of force is considered, that is, the double circular arc gear is forced before the teeth run-in. In the transmission of double circular arc gear, with the change of tooth width, the number of engagement teeth and the engagement position of engagement teeth are changing. Therefore, when establishing the finite element model, the APDL language of ANSYS is fully used to analyze the forces of gears with different tooth width. In order to obtain better bending stress characteristics, it is necessary to understand the change rule of bending stress when nominal pressure angle, tooth profile process angle and full tooth height change.

Therefore, some discrete points are taken as the action points of force, the direction of force is taken as the direction of tooth length, and the normal of tooth surface is added to the theoretical meshing point. Finally, in order to better simulate the actual boundary conditions, the lower half of the pinion and the three directions of the two ends of the pinion in the double circular arc gear are completely fixed, while the two boundary lines on the inner hole of the big gear are fixed along the normal direction, even if the big gear can only rotate on the pinion and cannot move, as shown in Fig.7.

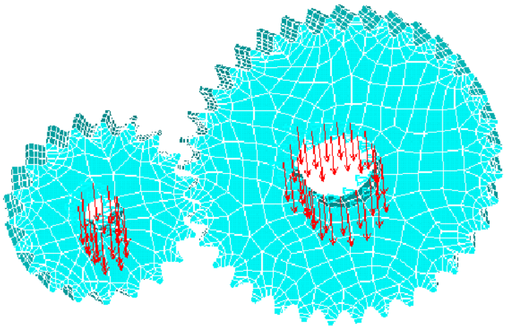


Fig.7 Boundary Conditions and Application of Loading

5.3. Result analysis

Fig.8 shows the curves of maximum contact stress varying with nominal pressure angle in several groups of double circular arc gears. When the tooth width of double circular arc gear is fixed, its maximum contact stress increases with the increase of helical angle, and it can be concluded that if the helical angle increases, the increase of contact stress is obvious. When the full tooth height of double circular arc gear increases gradually, the maximum contact stress decreases gradually.

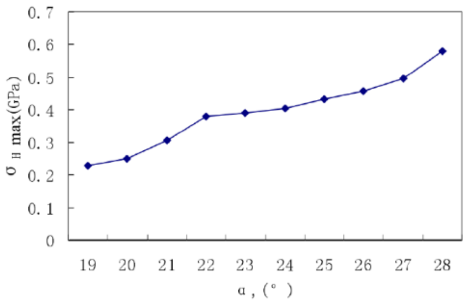


Fig.8 The influence curve of nominal pressure angle on contact stress

VI. Conclusions

CAE technology has been well applied in the paper. This paper takes gear pair as the research object, carries on ADMAS dynamics simulation to the generated double circular arc gear, obtains the linear velocity curve of the double circular arc gear, thus can understand its transmission characteristics. Finite element modal analysis and contact analysis are carried out in ANSYS. It is concluded that circular arc gears have high contact strength and bending strength.

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