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Study on Finite Element Method in Temperature Characteristic Analysis of Gear Pairs

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ABSTRACT :*A variety of theoretical analysis methods have been synthetically applied in the paper, and the calculation method of thermal load of gear pair in meshing process has been obtained, including friction heat flux and convective heat transfer coefficient. Combining with finite element analysis software ANSYS, the transient temperature field of gear pair in transmission process has been simulated under various conditions. From the analysis results, it can be seen that the heat of gear pair in transmission is the most. The large position is near the involute of the pinion, and the heat generated by friction increases linearly with the increase of speed and torque. The research method has important significance for reliability design of helical gear pair.*

KEYWORDS -*temperature field, ANSYS, gear pairs, finite element analysis*

I. INTRODUCTION

Gear pair is one of the most important transmission modes for mechanical equipment to complete high speed and high torque transmission. The transmission mode has good meshing, smooth transmission, low noise and large coincidence degree, which improves the load-carrying capacity [1]. In practical engineering, the analysis of gear pair is very important, and the analysis of temperature field is an important method to ensure the stability and life of gear [2]. Because the load and other factors in the transmission process change with time, the steady thermal analysis of gears cannot meet the actual working conditions. To solve this problem, the transient temperature field of helical gears under different working conditions is analyzed based on finite element method [3]. By studying the influence of the working conditions of the driving wheel (speed, torque) on the temperature field of the gear pair, the position which is easy to produce gluing is obtained to avoid the failure of the gear due to excessive temperature.

II. THERMAL LOAD ANALYSIS OF GEAR PAIRS

2.1 Friction heat flux

There are three kinds of friction on the contact surface of gear pair in the transmission process: sliding friction, rolling friction and friction caused by tooth shape change. Friction makes the gear pair produce heat and the meshing surface temperature rise. Because the heat generated by friction caused by rolling friction and tooth shape change is very small and negligible compared with sliding friction, the thermal load caused by sliding friction factors is studied in this paper. The calculation process is based on friction power method [4].

In the helical gear pair of this paper, the pinion is the active wheel, the big gear is the driven wheel, and the contact load between them is the action force and reaction force.The sliding friction force of gear pair is mainly determined by sliding friction coefficient and the pressure from meshing to meshing in gear transmission. Because the pressure changes instantaneously, in order to analyze and solve the heat generated by sliding friction, the average pressure stress in meshing contact area is used as the calculation value. The average contact compressive stress in the meshing contact area is directly related to the comprehensive elastic modulus, curvature radius of the gear pair and the load per unit length of the gear contact line along the tooth surface [5].According to the friction power method, the thermal power per unit area of gear in meshing area is related to sliding friction coefficient, average pressure and the speed of gear moving along the tooth profile at the meshing point, so the average thermal power per unit area of meshing area is not constant.

In this paper, the loss of heat generated in the air is neglected. It is assumed that all the heat generated by sliding friction of gears flows into gears. Because the material, thermal conductivity and dimension parameters of the two gears are different, the heat flow into the two gears is different. In order to calculate the inflow of heat generation more reasonably, it is necessary to introduce the calculation of heat distribution coefficient.

2.2. Convective heat transfer coefficient

Lubricating oil plays an important role in gear transmission mechanism. It controls convective heat transfer through its lubrication and cooling function, and keeps the maximum temperature of gear basically in equilibrium under stable working condition. Generally speaking, the convective heat transfer coefficient of the gear tooth surface is lower than that of the end face.There are many methods and theories for calculating the heat transfer coefficient on the surface of gear teeth. This paper uses Blok theory to calculate the heat transfer coefficient [6]. This method obtains the value of convection heat transfer coefficient according to the lubricant parameters.The convective heat transfer coefficient of the gear end surface is related to the motion viscosity of the lubricating oil, the heat conduction coefficient and the gear speed. For the convective heat transfer coefficient of the gear end face, Hartnett's formula is used to calculate it.

III. NUMERICAL SIMULATION OF TRANSIENT TEMPERATURE FIELD

3.1. Establishment of finite element model

In this paper, a three-dimensional model of helical gear is established based on Pro/E, and APDL is imported through the seamless interface between ANSYS, and the finite element model is obtained as shown in Fig.1. For the establishment of helical gear pair model, the scanning method is used in this paper. Firstly, the top circle and root circle of helical gear are created according to the parameters of gear pair, and the single tooth profile is established by multi-point fitting of involute. Then, the helix of helical gear is drawn and the tooth profile is scanned along the helix. Finally, helical gear parts are created by array processing. In the assembly mode, the meshing and contact of the tooth surface are completed by setting the "cam" mechanism.

In ANSYS, a special thermal analysis unit, Thermal Solid 20node 90, is selected by using the transient analysis module. Thermal-mechanical coupling adopts the sequential coupling method. After defining the material parameters related to temperature, tetrahedron meshing is carried out. In this paper, the method of global free partition and meshing area local mesh optimization is used to partition the mesh. Finally, 418650 elements and 693550 nodes are obtained.

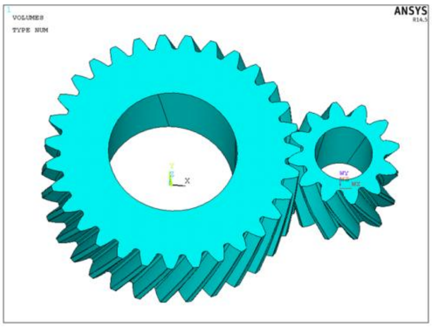

Fig.1Finite element model of gear pair

3.2. Load and boundary conditions

In ANSYS thermal analysis, load conditions mainly include three parts: ambient temperature, heat flux and convective heat transfer coefficient, in which both heat flux and convective heat transfer coefficient are surface loads. In the analysis of transient temperature field, the thermal load is set as follows. Set the working environment temperature of gear pair to 60 ℃. The heat flux of the gear pair is applied to all the teeth engaged in meshing in the transmission process. The convective heat transfer coefficient on the tooth surface and the convective heat transfer coefficient on the gear end face are applied to the non-contact tooth face and the gear end face position which are not engaged in meshing, respectively, as shown in Fig.2.

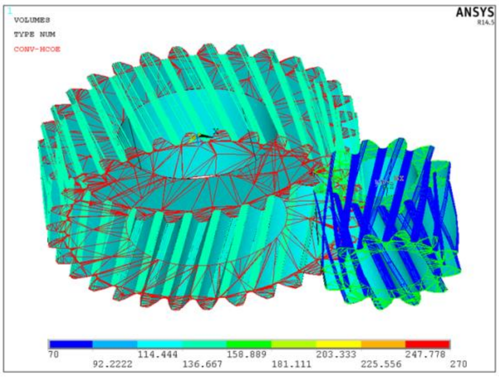

Fig.2Load and boundary conditions setting

In the setting of boundary conditions, the internal surfaces of the two gears in the gear pair only retain the degree of freedom of rotation of Z axis. In this paper, the rotation direction and angular displacement of the driving wheel and the driven wheel are set by establishing the cylindrical coordinate system and the node coordinate transformation [7]. In order to analyze the whole period, the angular displacement is set to be 2π.

3.3. Result analysis

Through finite element calculation, the transient temperature field cloud of helical gear pair is obtained as shown in Fig.3. It can be seen from the figure that the highest temperature value of gear pair is 150 ℃. The high temperature area is distributed on the contact surface where the active gear engages. The temperature is directly related to the heat flux load. The temperature gradient on the contact surface is the highest, which is due to the obvious heat dissipation effect of lubrication under the load of heat flux density. The temperature gradient of the non-contact tooth surface without engagement is higher than that of the gear face, which is lower than that of the meshing tooth surface. This is because the non-contact surface is close to the contact surface and is greatly affected by the heat flux. Under the action of convective heat transfer, the temperature changes greatly. The lowest temperature of the gear pair in the nephogram is 60 ℃, which distributes with the inside and end face of the gear. This is because the influence of heat flux on the end face of the gear is the smallest, and the condition of heat dissipation is good, which is close to the environmental temperature.

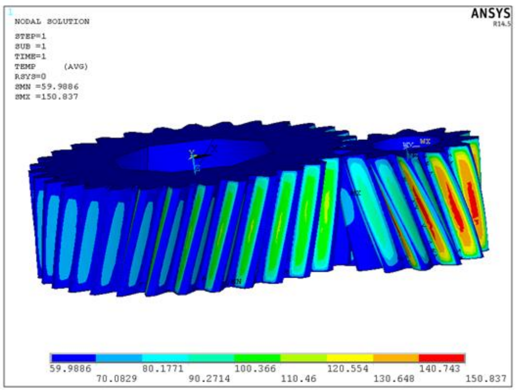

Fig.3Analysis results of temperature field

IV. COMPARISON OF TEMPERATURE FIELD UNDER DIFFERENT WORKING CONDITIONS

4.1. Rotational speed condition

In order to study the influence of the speed of the driving wheel on the maximum transient temperature, the same method is used to set the ambient temperature at 40 ℃. In the same analysis step time, the steady temperature field of the gear pairs with the speed of the driving wheel at 480 r/min, 960 r/min, 1440 r/min and 1920 r/min is analyzed respectively. Finally, the relationship between the maximum temperature and the speed of the driving wheel is obtained as shown in Fig.4.In Fig.4, it can be seen that the heat generated on the contact surface of helical gears increases with the increase of rotational speed. The maximum temperatures of contact surfaces of helical gears at four different rotational speeds are 130℃, 202℃, 278℃ and 354℃, respectively, showing a linear trend.According to the calculation formulas of friction heat flux and surface convection heat transfer coefficient of gears, it can be seen that when the speed of gears changes to 4 times of the original speed, the corresponding friction heat flux of gears also changes to 4 times of the original, while the convection heat transfer coefficient changes to 2 times of the original, which is consistent with the analysis results.

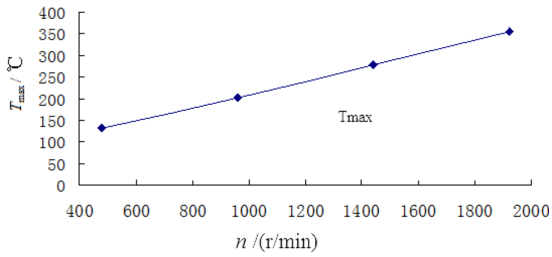

Fig.4 Relationship between maximum temperature of contact tooth surface and speed of driving wheel

4.2. Torque condition

In order to study the influence of the driving wheel torque on the maximum transient temperature, the steady-state temperature field of the gear is analyzed when the driving wheel torque is 38N·m, 78 N·m, 118N·m and 158 N·m, respectively. Finally, the relationship between the maximum temperature and the driving wheel torque is obtained as shown in Fig.5. As can be seen in Fig.5, with the increase of the driving wheel torque, the temperature extreme value increases, and the maximum temperature of contact tooth surface of helical gear pair under four different torque conditions is 124 ℃, 159 ℃, 186 ℃ and 208 ℃, respectively, which also shows a linear growth trend.

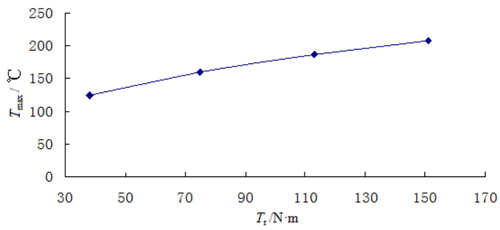

Fig.5 Relationship between maximum temperature of contact tooth surface and driving wheel torque

V. CONCLUSION

In this paper, the transient temperature field of helical gear pair in transmission is studied that caused by the change of speed and torque. The frictional heat flux and convective heat transfer coefficient in gear transmission are calculated by friction power method. The calculated values are imported into ANSYS in the form of thermal load. The transient temperature field is simulated under the working conditions of 480 r/min, 960 r/min, 1440 r/min, 1920 r/min and 38·N m, 78 N·m, 118 N·m and 158 N·M respectively. The results show that the rotational speed and rotation are different. With the increase of the moment, the temperature extreme value of the contact tooth surface increases and presents a linear growth characteristic.

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