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Quenching Process Simulation of Spur Gear Based on ANSYS

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Abstract. Gear transmission is one of the most common mechanical transmissions in contemporary machinery. It is the main form of transmission of mechanical power and movement, and it is an important part of all kinds of machinery. For gear transmission, better hardness and wear resistance are required, which can be achieved by quenching process. But the spur gear in quenching process, its size and shape will appear different degree of deformation, this paper uses the Pro/Engineering software to establish solid parameterized model of the spur gears. Then, the simplified single tooth solid model of the spur gear imported to ANSYS software to obtain the finite element model. The temperature field of the single tooth spur gear during quenching were carried out. Thus, it is concluded that the relationship between the factors influencing the quenching. The results provide a certain reference basis for the establishment of the hot working processes of the spur gear.

1. Introduction

Spur gear is one of the most common mechanical parts in modern machines. Spur gear hardening is used to make gear with hard tooth surface in order to improve the hardness and bearing capacity of the spur gear. In the heat treatment process of harden tooth surface, the same torque of hardened gear is transferred. It makes smaller in size, lighter in weight and lower in cost, so it becomes the main processing method [1, 2].

At present, many scholars have studied the quenching process of the spur gear. Song used ANSYS software to simulate and analyze the surface quenching of a spur gear, and obtained the results of temperature field, thermal stress and thermal deformation in the quenching process of the spur gear [3]. Zhang conducted simulation analysis on the quenching process of a cylindrical gear. The conclusions are that the tooth center temperature of the cylindrical gear is the highest, the tooth top temperature is the lowest, and the stress is mainly concentrated in the tooth root [4]. Wang summarized the shortcomings of traditional quenching process; combined with the computer simulation technology, put forward the numerical simulation of gear carburizing and quenching process as the development direction of the current industry [5]. The paper takes a spur gear as the research object, establishes the three dimensional model of the spur gear by using Pro/Engineering and imports it into ANSYS for quenching numerical simulation analysis. The quenching process of spur gear was studied and analyzed from the aspects of temperature field. It provides a certain reference for the formulation of gear hot working technology.

2. Spur Gear Three Dimensional Modelling

The software Pro/Engineering is used to establish three dimensional solid model of a spur gear. By measuring the dimension of gear, the main dimension parameters are obtained. Module of the spur gear is 3 mm, teeth is 25, tooth profile angle is 20 °, thickness of the spur gear is 20 mm, high coefficient of the spur gear is 1.0, tip clearance coefficient of the spur gear is 0.25. The three dimensional geometric model of the spur gear is established by using Pro/Engineering software. The three dimensional model of the spur gear is shown in figure1.

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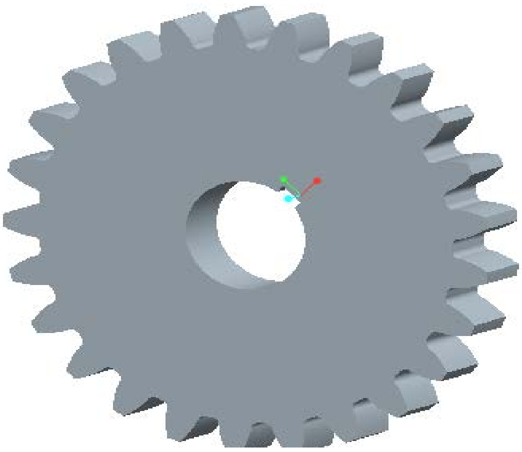

Figure 1. Three Dimensional Model of the Spur Gear

In order to save space and improve the simulation speed, a simplified single tooth three dimensional model of the spur gear was established by using Pro/Engineering. The single tooth model of the spur gear is shown as figure 2.

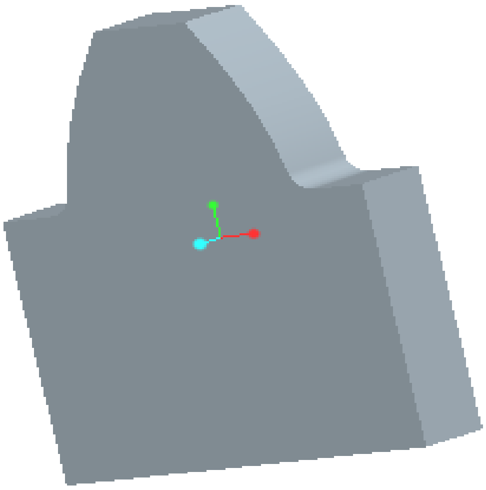

Figure 2. Single Tooth Model of Spur Gear

3. Thermodynamic Parameters of Materials

The material of spur gear is 20CrNi2MoA. The density, specific heat capacity, heat conductivity and other parameters of the material is given as table 1.

Table 1. 20CrNi2MoA Thermal Parameters

Density ρ (kg/m3)	20℃			7820			
Specific heat capacity Cρ (J(Kg.k))				460			
Temperature t(℃)	0	100	200	400	600	800	1000
Thermal conductivity Γ(w/(m.k))	14.7	16.6	18	20.8	23.5	26.3	26.8

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The analysis of the spur gear quenching process by ANSYS also needs to provide mechanical performance parameters at different temperatures, such as elastic modulus, yield strength, poisson's ratio, and coefficient of linear expansion and shear modulus. Tab.2 gives the mechanical parameters of 20CrNi2MoA [6].

Table 2. 20CrNi2MoA Mechanical Parameters

temperature T /℃	Elastic modulus E(Pa)	Shear modulus G(Pa)	Yield strength Δ(Pa)	Coefficient of linear expansion 1/℃	Poisson ratio
20	1.93e11	1.93e10	0.2e9	1.78e5	0.29
500	1.5e11	1.5e10	0.933e9		
1000	0.7e11	0.7e10	0.435e9		
1500	0.1e11	0.1e10	0.07e9		
2000	0.01e11	0.01e10	0.007e9		

4. Mathematical Model of Quenching Process

During quenching, the heat transfer mode includes heat conduction and heat convection. In the three dimensional rectangular coordinate systems, the heat conduction equation is shown in equation (1). Heat conduction is the exchange of heat between two bodies in complete contact or between different parts of an object due to a temperature gradient. Heat transfer follows Fourier theorem.

$$\frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right)+q_v=\rho c\frac{\partial T}{\partial t} \tag{1}$$

Here:
ρ is the density of the material;
λ is the heat conduction coefficient;
c is specific heat capacity;
q_v is latent heat of phase change;
T is the temperature.

For the spur gear quenching process, heat conduction coefficient, specific heat capacity and material density are related to the temperature in quenching process. The heat flux, temperature, thermal boundary conditions and internal energy in the transient heat transfer system all change with time [7]. According to Fourier law, the transient heat transfer formula is shown in equation (2).

$$[C]\{t^k\}+[k]\{t\}=\{q\} \tag{2}$$

Here:
$[k]$ is heat transfer matrix;
$\{t^k\}$ is the time derivative of temperature;
$[C]$ is specific heat capacity matrix;
$\{q\}$ is the node heat flux vector, including heat generation.

5. Temperature Field Analysis and Discussion

For the general heat conduction problem, the content of single value condition includes physical condition, geometric condition, initial condition and boundary condition. Geometric conditions refer to the geometric dimensions and shapes of the spur gears involved in the heat conduction process. Physical conditions are the main physical parameters and physical characteristics of the spur gear guiding heat. Questions such as whether the physical parameters vary with temperature, whether there is an internal heat source, whether they are evenly distributed and so on. The initial condition refers to the temperature field in the spur gear at the beginning of heat conduction process. The boundary condition is to guide the heat exchange between the hot spur gear and the external environment.

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The model was imported into ANSYS for pre-processing, including material property setting, grid division and material parameter setting. Finite element mesh generation is the transformation of geometric model into a finite element model composed of nodes and elements. The density of grid can be adjusted by controlling the size of unit and dividing precision. Automatic mesh generation method is adopted for mesh generation of the spur gear model. The final single tooth finite element model is shown in figure 3.

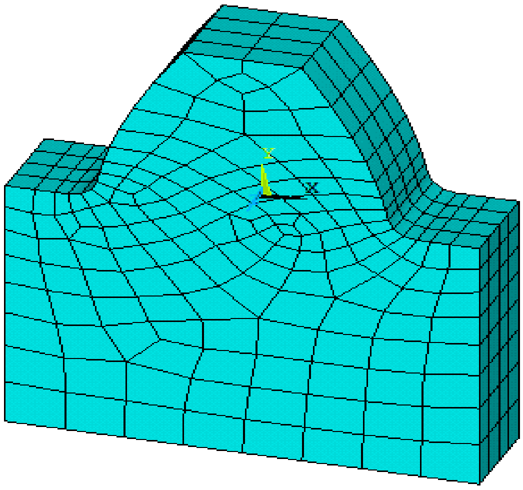

Figure 3. Single Tooth Finite Element Model

The single tooth spur gear with the initial temperature of 850℃ is quenched in the oil tank with the ambient temperature of 25℃. The analysis of temperature field set the time as 3 minute and the time interval as 10 second. The cloud graph of temperature field distribution at quenching time intervals between 30 second and 120 second is given, as shown from figure 4 to figure 7.

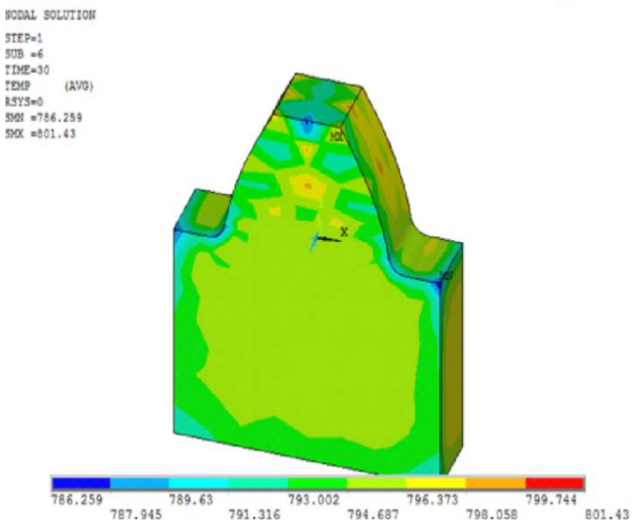

Figure 4. Cloud Graph of Temperature Distribution at 30 Second

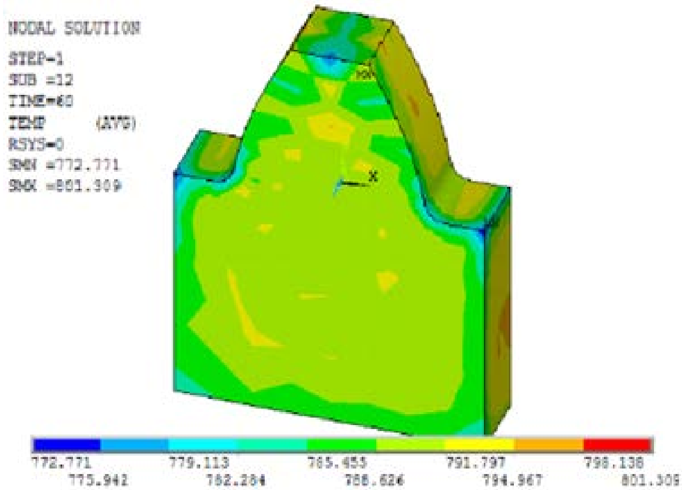

Figure 5. Cloud Graph of Temperature Distribution at 60 Second

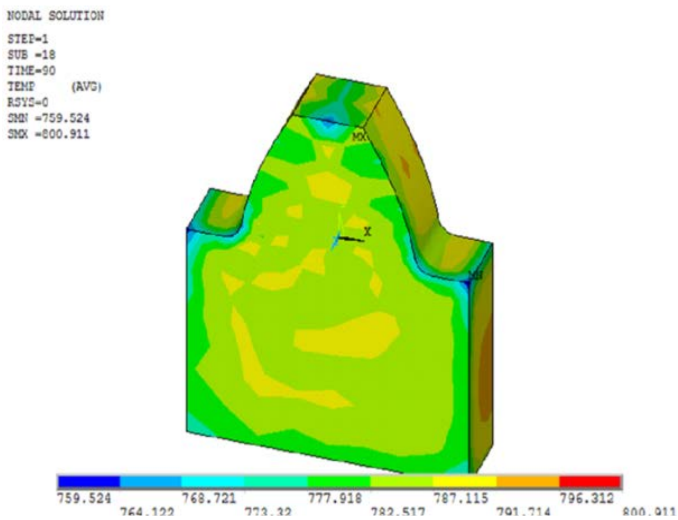

Figure 6. Cloud Graph of Temperature Distribution at 90 Second

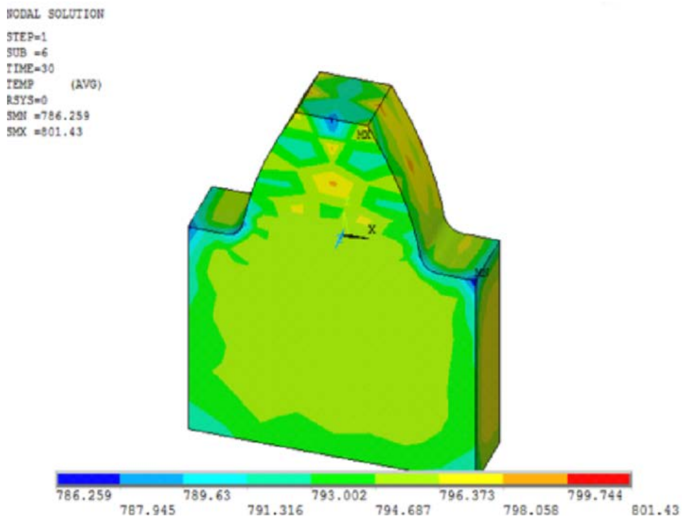

Figure 7. Cloud Graph of Temperature Distribution at 120 Second

It can be seen from figure 4 to figure 7 that the temperature difference between the tooth centre and the tooth surface is large. The difference between the maximum value and minimum value of the quenching temperature field of the gear at 10s is about delta 1=5℃. At the time 20s, the maximum value of the gear temperature field is about delta 2=10℃. At the time 60s, delta 3 is about 29 ℃. Therefore, it can be concluded that the temperature difference between tooth surface and tooth centre gradually increases with time, and the corresponding thermal stress is also gradually large, so it is the main process of accumulating thermal stress at the beginning of quenching.

In the quenching process of single tooth spur gear, the temperature difference between tooth surface and tooth centre is large, for the whole single tooth spur gear, the smaller size of the gear is more likely to cause the deformation of the gear, so in the single tooth spur gear processing time for small size gear, to ensure that there is enough machining allowance to ensure the function of the gear processing requirements.

6. Conclusions

According to heat transfer and finite element theory, a three dimensional heat transfer model of the spur gear is established to simulate real working conditions. By adding specific boundary conditions, the finite element analysis of gear quenching process is carried out based on the actual working conditions. The quenching temperature values of different time are obtained, which provides theoretical basis for further determination of gear quenching process. By analysis the temperature distribution of single tooth spur gear after quenching, the change trend of the temperature inside the gear can be obtained. The research results provide a certain reference for the design of the spur gear and the formulation of thermal processing technology.

7. Acknowledgment

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