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Research paper

Analysis model for surface residual stress distribution of spiral bevel gear by generating grinding

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ABSTRACT

Spiral bevel gears are the key parts of high performance power mechanical transmission system of heavy vehicles, aircraft engines and helicopters. In order to improve the carrying capacity and technique target of spiral bevel gears, it is necessary to study the surface grinding residual stresses of spiral bevel gears, so as to guide the grinding process of spiral bevel gears. An analysis model of surface residual stress based on generating grinding method for spiral bevel gears is proposed. The model can calculate tooth surface residual stress, considering the grinding state of each tooth point in the process of gear machining and the Johnson–Cook plasticity model of material. Supported by the proposed model, the distribution of surface residual stress of spiral bevel gear is analyzed. The model is verified by experimental data, the influence of grinding parameters on the surface residual stress is summarized, and the grinding optimization scheme is put forward.

1. Introduction

The spiral bevel gear is the main transmission part of the power mechanical transmission system, such as helicopters, aircraft engines and heavy haul vehicles, which has the characteristics of high speed, large transmission load, high energy density, severe shock and vibration, and complicated load change. It is a relatively weak power element in the transmission system. With the continuous development of power transmission systems such as aviation and vehicles, it is very important to improve the machining quality, bearing capacity and reliability of spiral bevel gear. Tooth surface residual stress is one of the important indexes of spiral bevel gear, which has a great influence on the gear deformation, corrosion resistance and fatigue strength.

Generative grinding is a widely used method for precision machining of gears, which is an important process to ensure the machining accuracy and surface quality. It is often used as the final process of gear processing. Residual stress on the surface after grinding has a significant influence on the performance of spiral bevel gears. Residual stress may strengthen the workpiece, or may cause cracks on the surface of the workpiece, reducing fatigue strength and corrosion resistance. In recent years, many researchers have studied the grinding residual stress. Bruno et al. drew a conclusion through a series of experiments that the thermal stress played a prominent role in the residual stress during the processing [1]. Deng and Murakawa developed 3-D and 2-D finite element models to simulate residual stresses based on the characteristics of temperature fields with ABAQUS software, and experiments were carried out to verify the correctness of the numerical models [2]. Ulutan et al. predicted the machining residual stress through an analytical model, considering the thermo-mechanical

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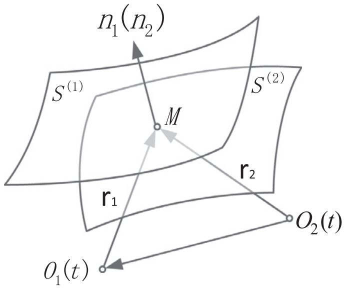

Fig. 1. The meshing drive of two moving surfaces.

coupling and the stress relaxation based on the elasto-plastic properties of the material, the computational efficiency of the model was greatly improved compared to that of finite element analysis [3]. Hamdi et al. studied the influence of grinding parameters on the residual stress of steel through simulating the stable grinding stage and the cooling stage after grinding, he found that the grinding temperature and residual stress were positively related to the grinding linear speed [4]. Fergani et al. proposed a physics-based model to study the temperature effects on residual stresses, which could provide an analytical tool for grinding process planning and optimization for control of tensile residual stresses [5]. Aiming at the calculation of grinding surface residual stress of spiral bevel gear, few researches have been done. Ming et al. calculated the grinding forces and the heat distribution ratio according to the NC grinding principle of spiral bevel gear, and simulated the transient temperature field by 3D finite element model of thermo-mechanical coupling [6]. On this basis, Zhou and Ming stressed on spiral bevel gear grinding surface residual stress modeling based on thermo-mechanical coupling, and analyzed its influence on the tooth surface crack [7]. However, due to complicated curved surface of spiral bevel gears, the grinding state of each part of the tooth surface is different in the process of generating grinding, the former 3D finite element model of thermo-mechanical coupling does not take into account this factor, and it is inefficient in calculation, therefore, it is necessary to further study grinding surface residual stresses of spiral bevel gears.

It can be seen that the research of grinding surface residual stress of spiral bevel gear has not been sufficient so far. In this paper, a mathematic model of grinding surface residual stress of spiral bevel gear was established, which was based on the generating principle of spiral bevel gear and thermal stress theory. This model considered the influence of the thermal field of tooth surface and mechanical cutting forces on grinding surface residual stress. Through this model, the distribution of tooth surface residual stresses was analyzed. Then the model was validated by grinding tests, and the way to controlling surface residual stresses of gear tooth was also discussed.

2. Generating grinding of spiral bevel gears

The grinding surface residual stress of spiral bevel gear is based on the process of generating grinding. This section mainly introduces the principle of the generating grinding of spiral bevel gear.

2.1. Meshing principle

Litvin and Fuentes, and Simon put forward the basic principle of spiral bevel gear generating. The grinding process of spiral bevel gear is based on the simulation of the grinding wheel and the meshing of the machined gear. In the grinding process, the surface of the grinding wheel is represented by a conjugate surface which is meshed with the machined tooth surface [8,9]. Assume that $S^{(1)}$ and $S^{(2)}$ are a pair of conjugate surfaces as shown in Fig. 1. The radius vector of point M on surface $S^{(1)}$ is $\mathbf{r}_1$, and the unit normal vector is $\mathbf{n}_1$. The radius vector of point M on surface $S^{(2)}$ is $\mathbf{r}_2$, and the unit normal vector is $\mathbf{n}_2$. It is assumed that in the space exist motion coordinate systems $\sigma_1(t)$ and $\sigma_2(t)$, $\mathbf{m}(t) = O_2(t)O_1(t)$ is the vector from the movement origin $O_2(t)$ of $\sigma_2(t)$ to the movement origin $O_1(t)$ of $\sigma_1(t)$, then $S^{(1)}$ and $S^{(2)}$ should satisfy Eq. (1):

$$\begin{cases} \mathbf{r}_2 = \mathbf{m}(t) + \mathbf{r}_1 \\ \mathbf{n}_2 = \mathbf{n}_1 \end{cases} \tag{1}$$

The above conditions ensure that the two surfaces contact each other at point M and are tangent to each other. In addition, the two contact surfaces should satisfy Eq. (2) at the contact position:

$$\mathbf{v}_{12} \cdot \mathbf{n} = 0 \tag{2}$$

where $\mathbf{v}_{12}$ is the relative speed of point M on $S^{(1)}$ and $S^{(2)}$. Satisfying the condition of the upper type can guarantee that the velocity components of the two moving surfaces are equal in the normal direction, so that the continuous engagement of the two surfaces can be ensured. Therefore, the tooth surface of generating gear represented by grinding wheel and the surface of the machined tooth surface should also meet the above two conditions.