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Analysis and Simulation of Spur Gear System Considering Geometric Eccentricity

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Abstract: Geometric eccentricity errors inevitably occur in gear systems, resulting in the center of mass and center of rotation not coinciding. During the gear meshing process, the gear center distance and gear tooth meshing condition will change with time. In this paper, a model considering geometric eccentricity is proposed and a finite element model of the gear pair is developed. Finally, the dynamic response under different eccentricity and initial eccentricity angle is discussed. Based on Ansys, the simulation calculation of the gear pair is carried out, and the equivalent force maps of the dangerous areas of the gear tooth flanks are obtained.

Keywords: Geometric eccentricity, finite element, stress, initial eccentricity angle, dynamic response.

1. Introduction

Automobile transmission is one of the key components affecting the performance of automobiles, as its main component of the gear transmission system performance will directly affect the performance of the car's various performance indicators. The main reduction gear of the automobile transmission is in a constant state of meshing, bearing all the torque of the automobile transmission, and due to the constant changes in speed and frequent gear changes, its working conditions are more complex and variable and the working environment is harsh. And the main reduction gear and transmission output shaft as a whole, is one of the key components of the automobile transmission, its life is generally the same as the whole car, and expensive, it is impossible to change at will. Therefore, it is necessary to analyze it scientifically.

In addition, the eccentricity due to manufacturing and assembly errors, such as runout errors, its will inevitably appear in actual gear systems. phadatare h p et al [1] analyzed the effect of mass eccentricity on lightweight flexible rotor-disk-rotor systems. zhao bai-shun et al [2] proposed a method for loaded gear tooth contact with improved eccentricity, and verified it. yuan bing et al [3] analyzed the quasi-static characteristics of helical gear system containing manufacturing error and runout error. In the previous studies [4, 5, 6], some scholars investigated the effect of eccentricity on the dynamic characteristics of the gear system; however, the effect of the initial phase on the dynamic response of the gear system was not analyzed in detail.

In recent years, scholars at home and abroad have done a lot of work on the dynamic characteristics of gear pair. C conducted a finite element modeling study to investigate the effects of gear design parameters on the dynamic characteristics of an automotive transmission system gear design parameters on the dynamic characteristics of automobile gearbox transmission system by means of finite element modeling [7]. Prof. Fang Zong de et al. Prof. Zong de Fang from Northwestern Polytechnic University studied the dynamic characteristics of helical gears [8].Prof. Fang Zongde and others from Northwest University of Technology studied the dynamic characteristics of helical gears [9]. Prof. Liu Geng studied the effects of gear parameters on the dynamic characteristics of helical gears [10].parameters of the gear pair on the vibration characteristics of external and internal helical gears [11].The effect of the parameters of the gear pair on the vibration characteristics of external and internal helical gear trains was investigated by Prof. Liu Geng [12]. Chen Jing and Shi wen have analyzed the dynamic simulation analysis of transmission gear system [13]. However, the gears have impacts in the actual working process, so the key part. However, the gears have impacts in the actual working process, so the stresses in the critical parts will also be generated with the fluctuation of some parameters in the meshing process. Fluctuation of some parameters in the meshing process, but the research in this area is not yet deep enough. However, the research in this area is not deep enough.

2. Dynamic Model with Geometric Eccentricity

Figure 1 illustrates a 2-dof parametric model of a pair of involute spur gear trains considering geometric eccentricity. In this model, the shaft, pinion and large gears are defined as rigid except for the teeth. The geometrical eccentricities of the pinion and the large mobile gear are ρ_p and ρ_g, respectively; the angular vibrations of the pinion and the large gear are θ_p and θ_g, respectively; O_p, and O_g are the centers of circles of the pinion and the large gear, respectively; G_p and G_g are the centers of rotation of the driving gear and the driven gear, respectively; m_i is the mass of the gear i $(i = p, g)$; J_i is the moment of inertia of the gear i relative to the center of rotation; ω_i is the nominal angular velocity of gear i; T_i is the torsional torque applied to gear i.

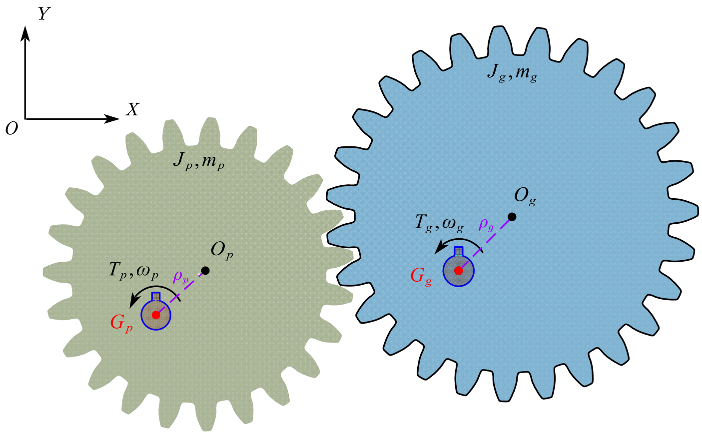

Figure 1. Parametric Modeling of Spur Gear Units with Geometric Eccentricity

When gears are geometrically eccentric, the geometric eccentricity error will affect the gear system and be reflected in the centrifugal and inertial forces [14].

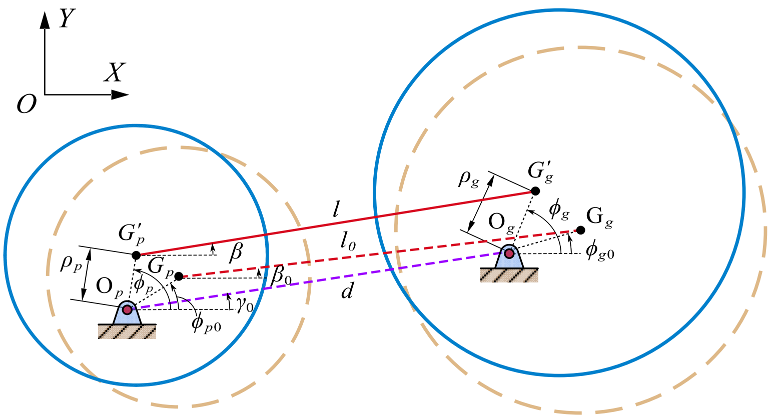

Figure 2. Generalized coordinates for the gear pair

Figure 2 describes the generalized coordinates for the mated gear pair. The motion of the gear set is rotary. The dashed and solid circles represent the gear pair before and after motion, respectively. Due to the presence of geometric eccentricity the initial center distance is d_0. γ_0 and γ are the initial and actual mounting angles of the large gear in relation to the pinion gear, respectively. Here, two static coordinate systems $O_i\ x_i\ y_i\ (i = p, g)$ are established on the axis centers O_p and O_g, respectively. The angle β represents the position of the gear relative to the pinion after motion. d is the actual center distance, l is the distance between the two centers of mass G'_p and G'_g after the motion of the gear pair. $\Phi_{p0}$and Φ_{g0} are the initial eccentricity angles.

The rotation angle displacements of gear i are given by angular coordinates, Φ_p and Φ_g,which can be expressed as follows:

$$\phi_p(t) = \theta_p + \phi_{p0},\ \ \phi_g(t) = \theta_g + \phi_{g0} \tag{1}$$

where θ_i is the torsional angle displacement superimposed on the rigid-body rotation of gear i.

The relationship between the coordinates of the center point and the center of rotation can be found from geometric relationships.

$$X_{G_p} = \rho_p \cos(\phi_{p0}),\ \ Y_{G_p} = \rho_p \sin(\phi_{p0}) \tag{2}$$

$$X_{G_g} = \rho_g \cos(\phi_{g0}),\ \ Y_{G_g} = \rho_g \sin(\phi_{g0}) \tag{3}$$

$$X_{G'_p} = \rho_p \cos(\phi_p),\ \ Y_{G'_p} = \rho_P \sin(\phi_P) \tag{4}$$

$$X_{G'_g} = \rho_g \cos(\phi_g),\ \ Y_{G'_g} = \rho_g \sin(\phi_g) \tag{5}$$

According to the gear mesh relationship, the dte (dynamic transmission error) between two mating gears along the loa which can be written as:

$$\delta_L = R_{bp}\Psi_p + R_{bg}\Psi_g \tag{6}$$

The equation of motion of the system is:

$$\left(I_p + m_p\rho_p^2\right)\ddot{\theta}_p + \sum_{\tau=1}^{n} T_{m_p}^{\tau} = T_p \tag{7}$$

$$\left(I_g + m_g\rho_g^2\right)\ddot{\theta}_g + \sum_{\tau=1}^{n} T_{m_g}^{\tau} = T_g \tag{8}$$

where τ is the number of contact teeth at any given moment.

3. Finite Element Modeling

Parameterization refers to the use of geometric constraints, mathematical equations and relationships to characterize the shape of the model. Characteristic refers to the parametric shape model composed of a set of geometric elements that carry certain engineering information and determine the geometric topological relationship for the application, which is the key element of parametric modeling [14]. In this paper, on the ansys software, we rely on its creative shape design module to create parameters and formulas, and rely on the part design module for modeling. The geometric model of the gear pair is shown in Figure. 3.

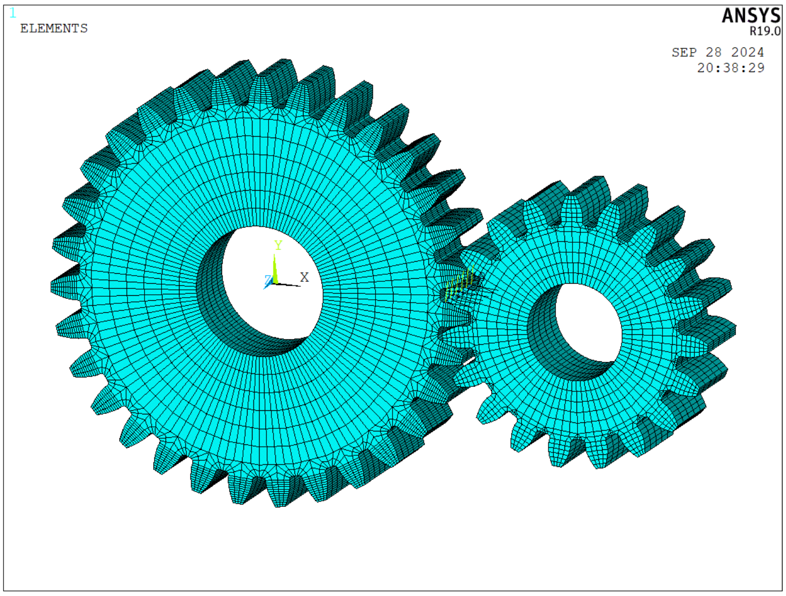

Figure 3. Finite element model

First, two reference points are established at the centers of the two gears, and then distribution coupling constraints are established between the respective reference points and the corresponding gear faces using the corresponding reference points of the two gears. The distribution coupling constraints are then used so as to simulate the relationship between the gear shaft and the gears. The positional constraints of the gear pair are set by the reference points to limit the displacement and rotation of the gear pair in the x and y directions.

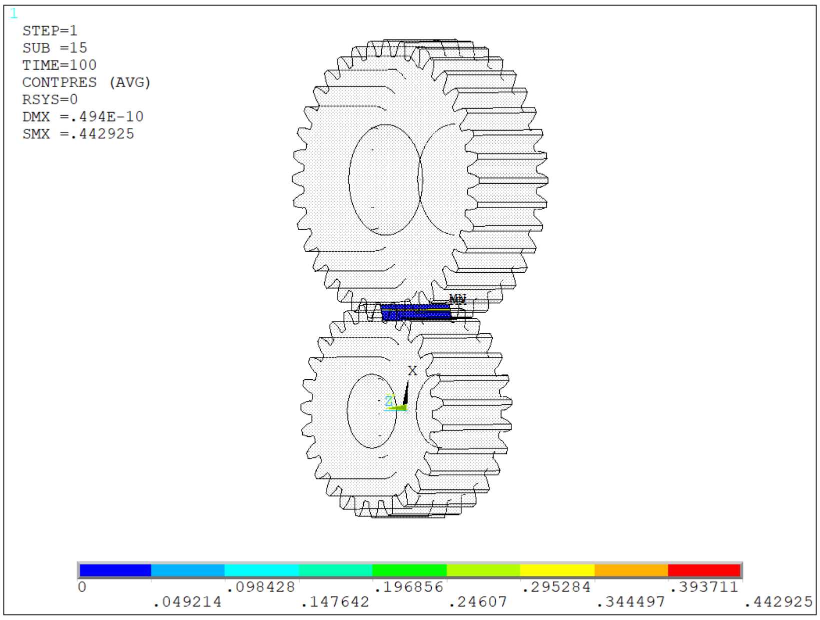

Figure 4. Setting up contacts

Setting up the contact in finite element analysis is very important because the contact is highly nonlinear and an unreasonable contact setup can lead to difficult or even non-convergence of the model.

4. Simulation Results and Dynamics Analysis

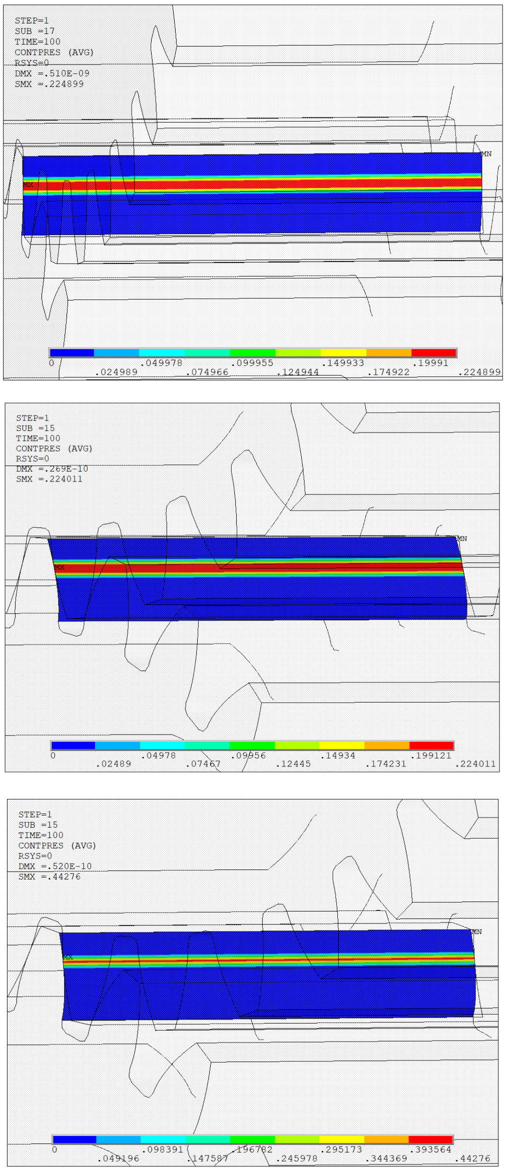

Figure 5. Stress clouds at different center distances

Figure. 5 shows the stress cloud on the tooth surface for different center distance. Due to the existence of geometric eccentricity the center distance changes and as the gear rotates the center distance changes periodically and there are maximum and minimum values. The first image is the stress cloud at standard center distance and the second and third images are the stress cloud at maximum and minimum center distance respectively.

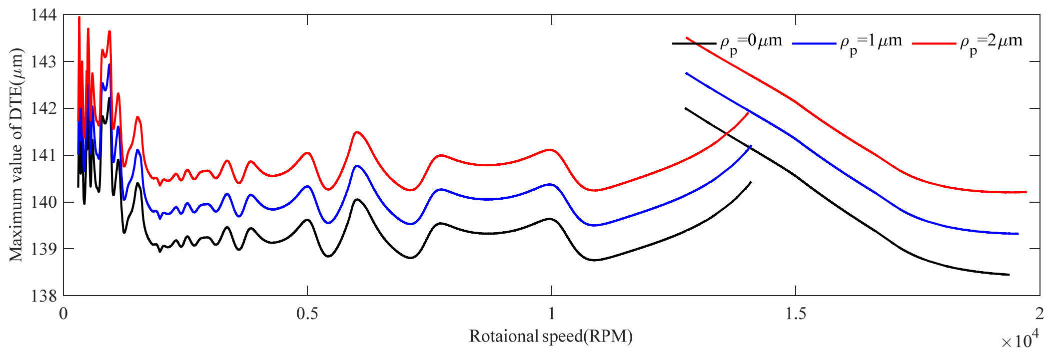

Figure 6. Frequency sweep at different eccentricity

The above figure shows the frequency sweep of different eccentricity, from which it can be seen that as the eccentricity increases, the frequency sweep curve also increases gradually. The jumping phenomenon occurs when the speed is around 13000rpm, which is due to the presence of tooth clearance.

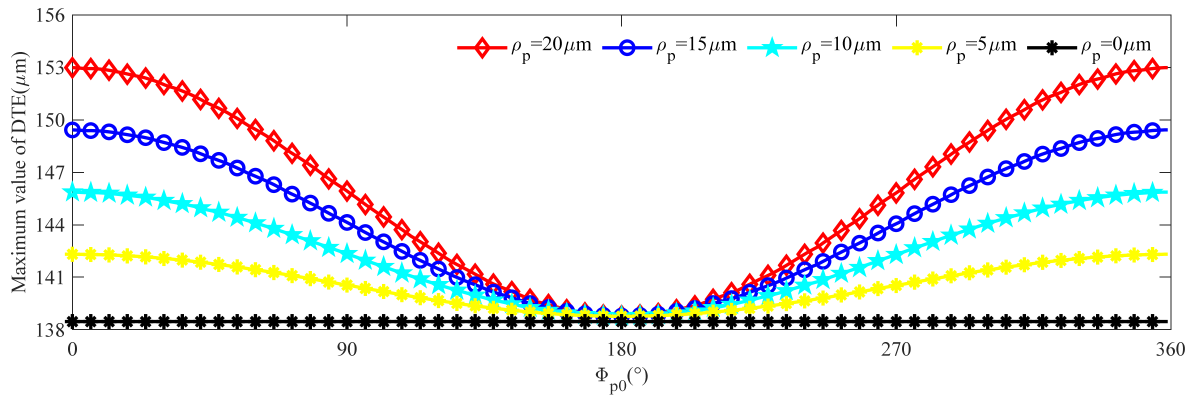

Figure 7. Dynamic response at different initial eccentricity call angles

Figure. 7 shows the frequency sweep of the initial eccentricity angle at different eccentricity rates, the initial eccentricity angle is fluctuating sinusoidally with 360° as a fluctuation period, and the larger the eccentricity rate the larger the image fluctuation. When the initial eccentricity angle is 180°, the dte is minimized at this time, when the eccentricity rate is certain, the reasonable placement of the eccentric gear can largely reduce the eccentricity fault on the dynamic response of the system, when the initial eccentricity angle of the eccentric gear is 180°, the impact is minimized.

5. Conclusion

Geometric eccentricity causes periodic changes in the center distance, which in turn affects the stress distribution on the tooth face. The presence of eccentricity leads to periodic fluctuations in dte, and the period of fluctuation is the rotation period. When the initial eccentricity angle of the large gear and pinion differs by "180°", a reasonable arrangement of the gear pair can reduce the vibration response of the gear pair and improve the stability of the system.

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