Analysis of Fatigue Characteristics of Gears Based on nCode DesignLife

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Abstract. For the phenomenon that the straight bevel gear transmission system is prone to fatigue failure under cyclic loading, the fatigue characteristics of gears are studied, and a fatigue damage simulation method is proposed. Taking a pair of straight bevel gear in driving line body as the research object, the dynamics analysis of the gear contact model was carried out through the ADAMS software, and the virtual load spectrum of the gear contact meshing was obtained. With the help of Workbench finite element analysis software, the gear static finite element analysis was performed to obtain the stress distribution and the weak points of fatigue of the gears. In nCode DesignLife software, the fatigue damage of the gear was estimated by loading the virtual load spectrum in the fatigue hazard area according to the nominal stress method. The stress concentration at the tooth roots of the gears obtained through simulation results in the risk of breakage of gear teeth, and the gears need to be optimized. The simulation provides reference for the fatigue reliability of the design, shortens the design cycle, and provides guarantee for the reliability of the line body.

1. Introduction

Gear transmission has advantages of stable transmission ratio, high transmission efficiency and reliable operation, which makes it widely used. Due to the structural characteristics of the gear and the transmission characteristics, the gear is prone to fatigue failure such as broken teeth and pitting on the tooth surface under repeated load for a long time. Therefore, the reliability of the gear transmission system has received much attention.

Most engineering structures or mechanical failures are caused by the accumulation of fatigue damage caused by a series of variable amplitude cyclic loads. Huang obtained the load spectrum based on the rain flow counting method and then used the Brown-Miller algorithm for fatigue damage analysis [1]. Ding based on the load spectrum simulated by the finite element method for fatigue life estimation [2]. Wang estimated the fatigue damage of herringbone gear based on rainflow counting method combined with Miner linear cumulative damage theory [3]. Li proposed a method for predicting structural fatigue life based on the multibody dynamics simulation and Finite Element Method [4]. M. Kamal [5] summarized a variety of fatigue damage estimation methods. According to the nominal stress method, based on the S-N curve of the material, the stress concentration factor and the nominal stress of the structural fatigue hazard area can be combined with the fatigue damage accumulation theory to calculate the fatigue damage [6].

2. 3-Dimensional Model

In gear transmission systems for assembly lines, metal gears and plastic gears are often paired to increase heat dissipation and reduce wear. The driving gear is made of SMF5040 powder metallurgy material
grade, and the driven gear is POM. Modeled in SolidWorks, the resulting 3D assembly model is shown in Figure 1.

3. Dynamic Model

Gear meshing transmission mainly relies on the impact force generated by contact collision [7, 8], including normal contact impact force and tangential friction force. The normal contact impact force can be calculated by the Impact function in ADAMS:

\[
F_n = \begin{cases} 
  K(x_1 - x)^e - \text{step}(x, x_1 - d, c, x_1, 0)x & \text{if } x \leq x_1 \\
  0 & \text{if } x > x_1 
\end{cases} 
\]

(1)

where \(K\) is the contact stiffness coefficient, \(x_1\) is the displacement switch to determine whether the one-side collision is active, \(x\) is displacement variables, \(e\) is the nonlinear spring force exponent, \(c\) is the damping coefficient, and \(d\) is the penetration depth of the two contact objects when the damping reaches the maximum.

Friction can be calculated by Coulomb function:

\[
F_f = -F_n \times \text{step}(v, -v_s, -1, v_s, 1) \times \text{step}(\text{ABS}(v), v_s, c_{st}, v_d, c_{dy}) 
\]

(2)

where \(F_n\) is the normal force, \(v\) is the relative sliding velocity, \(v_s\) is the stiction transition vel, \(v_d\) is the friction transition vel, \(c_{st}\) is the static coefficient, and \(c_{dy}\) is the dynamic coefficient.

According to the actual working conditions, the angular velocity of the driving gear is \(6.8 \text{ rad} \cdot \text{s}^{-1}\), the load of the driven gear is \(347 \text{ N} \cdot \text{mm}\), and both of them are increased gently within \(0.2\) seconds. The main parameter settings are shown in Table 1. The speed-time curve of the driven gear is shown in Figure 2. According to the rotational speed diagram of Figure 2, it can be seen that the rotational speed of the gear meshing basically satisfies the 1:1 relationship, indicating that the established dynamic model is feasible. Gear meshing force - time curve is shown in Figure 3.

**Table 1.** Set of Contact Force.

| K          | c   | \(v_s\) | \(v_d\) | \(d\) | e   | \(c_{st}\) | \(c_{dy}\) |
|------------|-----|---------|---------|-------|-----|------------|------------|
| \(3.0 \times 10^5 \text{ N} \cdot \text{mm}^{-1}\) | \(100 \text{ N} \cdot \text{mm}^{-1}\) | \(10 \text{ mm}\) | \(100 \text{ mm}\) | \(0.1 \text{ mm}\) | 2.2 | 0.1 | 0.05 |

From Figure 2 and Figure 3, the gear rotation speed is abrupt at the beginning, and the gear meshing force is also abruptly changed, and then the rotation speed and the contact force fluctuate around a level. The fluctuation of the driven gear speed and the contact force between the two gears is due to vibration and shock during the contact engagement.
4. Finite element model

Static contact simulation analysis can be calculated in Workbench. Considering the iterative calculations, it is necessary to speed up convergence [9]. Unreasonable solution of parameter settings and initial equilibrium condition settings will affect the convergence of the solution [10]. An angular displacement can be applied to the drive wheel and a load torque can be applied to the driven wheel. This setting facilitates solution convergence. The simulation results are shown in Figure 4.

5. Finite fatigue life

The fatigue damage of the gears was analyzed by using the CAE analysis software DesignLife from NCode, UK. It uses the nominal stress method as the theoretical basis to analyze the fatigue of the
component. The basic principle of the analysis is: the stress-strain results obtained by static analysis of the components using finite element analysis software are combined with the S-N curves of the component materials, and then the fatigue estimation theory is applied to calculate the distribution of fatigue damage of the components throughout the components.

Establish a fatigue analysis modal in nCode DesignLife software and calculate gear fatigue damage values. The finite element static analysis file of the powder metallurgy gear obtained in the workbench was imported into the FEInput module, and the gear meshing load spectrum file obtained by the dynamic simulation in the ADAMS was input into the SNAnalysis module through the Time Series, and the S-N curve of the material was input. Finally, the fatigue damage of the gear was obtained. The flow diagram of analysis is shown in Figure 5. And the simulation results are shown in Figure 6.

![Flow diagram of fatigue damage analysis](image1)

**Figure 5.** The flow diagram of fatigue damage analysis.

![Fatigue damage distribution nephogram of original gear](image2)

**Figure 6.** Fatigue damage distribution nephogram of original gear.

![Fatigue damage distribution nephogram of optimized gear](image3)

**Figure 7.** Fatigue damage distribution nephogram of optimized gear.

It can be seen from Figure 6 that the root of the tooth is the weak point of the gear, and the stress concentration is easy to occur here. The position with the node number 7019 is the most dangerous, and its damage value is $6.347e^{-9}$. Therefore, measures need to be taken to improve the gear structure and reduce the stress concentration. For the root stress concentration problem, the gear is redesigned and the fatigue analysis is carried out. The fatigue damage diagram of the optimized gear is shown in Figure 7.
It can be seen from the figure that the maximum damage value is reduced from the original $6.347e^{-9}$ to $1.582e^{-12}$, indicating that the structural optimization direction is reasonable.

6. Conclusion
In this paper, the powertrain assembly line is taken as the research object. The main research content is the fatigue damage analysis of the bevel gear transmission system in the conveyor line. The fatigue stress analysis of the gear of the transmission system is carried out by the nominal stress method. A series of simulation analysis of the gears was carried out, and the fatigue damage distribution cloud map of the parts and the specific values were obtained. The main conclusions are as follows:

(1) Based on the Adams dynamics simulation software, the simplified dynamic model of the bevel gear transmission system is established. The simulation of the transmission system under normal working conditions is carried out. The rotation speed-time course curve of the driven gear and the meshing force curve between the two gears are obtained. The correctness of the collision coefficient setting when the dynamic model is established is verified by the rotational speed diagram of the gear.

(2) The finite element analysis model of the bevel gear is established, and the stress distribution cloud diagram of the bevel gear is obtained. The dangerous part of the bevel gear is determined, which provides the directionality for the subsequent fatigue damage analysis.

(3) The process of fatigue damage analysis of bevel gears was built in nCode DesignLife. The finite element analysis results and load spectrum were imported into the input module, and the material properties and simulation parameters were set. After the analysis, the fatigue damage distribution cloud diagram of the bevel gear is obtained, which is consistent with the stress distribution cloud map. It provides an important basis for the structural design of the bevel gear. After optimizing the three-dimensional model of the gear, the gear fatigue damage value is reduced and the gear life is increased. The simulation verifies that the method can effectively verify the rationality of the gear design, shorten the design period of the gear, and guarantee the reliability of the line body.

7. References
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