Helical Modification and Analysis of Straight Spur Gear

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Abstract—It is difficult to solve the issue of uneven load distribution and improve the bearing capacity and reliability for straight spur gear pairs with small load and large axial deviation. Thus, some experts put forward the method of helical modification, but few people conducted simulation analyses to apply and verify the method. Therefore, based on the finite element analysis technology, helical modification is applied and the modification effect is evaluated. In addition, conducting comparative analysis and contact fatigue analysis for a pair of gears, it is verified that helical modification can solve the issue of uneven load distribution and improve the reliability of gear pair.

Keywords—helical modification; uneven load distribution; finite element analysis; fatigue analysis

I. INTRODUCTION

Generally, common crowning modification is often conducted for straight spur gears to solve the issue of uneven load distribution. With the development of CAE (Computer Aided Engineering), numerous researchers have performed simulation analyses to verify the effectiveness of crowning modification. However, as for gear pairs with small load and large axial deviation, crowning modification can’t improve the performance of them. In view of this situation, there were some people proposed helical modification for straight spur gears [1], and it can solve the issue of uneven load distribution. But few people verified the method by performing simulation analysis, thus finite element analysis is conducted in this paper to explore the effectiveness of this method. Because tooth surface is complex after modification, it becomes key problem to establish the model of gear pair with helical modification accurately.

Many experts have studied how to build model for gear pair with modification, such as Ferenc [2] proposed a novel mixed modeling method based on the principle of machining and the method of surface fitting. Yan Yang [3] established model of modified gear in Solid Works, and the 3D digital design system was developed based on Solid Works API. With respect to the simulation analysis for exploring the performance of modified gear pairs, Li J L and Tang JY [4, 5] deduced the tooth surface equation for gear with crowning modification, and TCA (Tooth Contact Analysis) was conducted to research the effects of modification. Besides, finite element analysis was performed by Yumei Hu [6] according to explicit dynamic method, and the effects of modification parameters and helix angles on the meshing performance were researched. Moreover, Zhengu Shang [7] built the finite element model for helical gears in ANSYS, and the influence of different modification methods on gear unit was obtained by observing the distribution of load and stress.

Tooth surface of modified gear is created accurately in this study, and then the solid model is established based on bottom-up modeling approach. After meshing the solid model and applying loads and constraints, transient analysis is conducted to gear pair with helical modification. And the modification effects can be acquired by observing the distribution of stresses and the position as well as the shape of contact area. In addition, comparative analysis is applied for a pair of gears when it is modified with helical modification, general crowning modification and without modification. Furthermore, contact fatigue analysis is performed for the gear pair with helical modification. Thus, the effectiveness of helical modification is verified.
II. METHOD OF HELICAL MODIFICATION

If the load of gear transmission is light and the axial deviation is large, tooth deformation because of contact is small. In this situation, the tooth pair with general crowning modification looks like the dotted line as shown in Figure 1. It can be observed that the contact area between the meshing teeth is still small because crowning modification amount is greater than the value of contact deformation. And it can’t solve the issue of uneven load distribution well.

Using helical modification method to improve the performance of straight spur gears as well as bearing capacity, and modified tooth pair looks like the solid line shown in figure 1. $F_{βγ}$ represents axial deviation in gear units, and $c_c$ is modification amounts in general crowning modification. As for conducting helical modification for gear pairs, the smaller gear needs to be deflected a certain angle along the direction of axial deviation, and the angle is called helical modification amount $c_h$. It can be found that the actual axial deviation is $F_{βγh}$ after modification. Besides, $c_c$ represents the crowning modification amounts in this method, and $b$ is tooth width. According to the reference [1], $c_c$ as well as $c_h$ can be calculated based on follow equations:

$$c_c = 1.5 \frac{F_m}{b \cdot C_γ} \tag{1}$$

$$c_h = F_{βγ} - \frac{F_m}{b \cdot C_γ} \tag{2}$$

where $F_m$ is peripheral force of gear, and $C_γ$ represents meshing stiffness.

Cylindrical coordinate system can be created by regarding the starting point of involute line located at the gear face as the origin of coordinate, and Z axis coincides with the direction of tooth width. If there is a point $N_{ki}$ which is located at $k$ section of gear tooth with helical modification, its coordinates can be represented by equation (3):

$$
\begin{align*}
  r_{ki} &= \frac{r_b}{\cos α_{ki}} \\
  θ_{ki} &= \left(\tan α_{ki} - α_{ki} + \frac{c_{ck}}{r_a}\right) \cdot \frac{180}{π} \\
  z_{ki} &= b_k
\end{align*}
$$

In the equation, $r_b$ is base radius, the pressure angle of point $N_{ki}$ is $α_{ki}$, $c_{ck}$ represents crowning amount of section $k$, $r_a$ is outside radius, and $b_k$ is the distance between coordinate origin and $k$ section.

III. TRANSIENT MESHING ANALYZING OF MODIFIED GEAR PAIR

In this study, it is key problem to create model and conduct transient meshing analysis for straight spur gear pair with helical modification, thus modification effects and meshing performance can be observed from analysis results. On the basis of previous studies [8, 9], calculating the coordinates of
points on tooth surface with helical modification, and points matrix can be established in ANSYS. Then the tooth surface can be fitted. On this basis, mesh model of gear pair with helical modification can be created as shown in Figure 2.

![Mesh model of gear pair](image1)

**Figure 2. Mesh model of gear pair**

Applying loads and constraints to the model of modified gear pair, transient analysis can be conducted. When the analysis is finished, equivalent stress contour map of gear pair with helical modification is as Figure 3. And the distribution of equivalent stress can be observed from the figure. In addition, some results such as contact stress can also be obtained. Thus, helical modification effects can be acquired by observing these results.

![Equivalen stress of gear pair](image2)

**Figure 3. Equivalent stress of gear pair**

### IV. APPLICATION EXAMPLE

#### 4.1 Comparative analyzing

There is a pair of gears which parameters are shown in Table 1, applying helical modification to the gear pair and transient meshing analysis is carried out. Meshing performance is obtained when the analysis is finished. Moreover, in order to effectively indicate the effect of helical modification on improvement of uneven load distribution, and the advantages compared to general crowning modification, comparative analysis is conducted when the gear pair is modified with helical modification and general crowning modification or without modification. Thus, simulation analysis is conducted respectively in these three situations. And the details are as follows.
### Table 1. Parameters of gears

<table>
<thead>
<tr>
<th></th>
<th>Drive gear</th>
<th>Driven gear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tooth number</td>
<td>20</td>
<td>63</td>
</tr>
<tr>
<td>Modulus $m$</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Pressure angle $\alpha$ (°)</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Modification coefficient</td>
<td>Drive gear $x_1$</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Driven gear $x_2$</td>
<td>0.25</td>
</tr>
<tr>
<td>Tooth width (mm)</td>
<td>Drive gear $B_1$</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Driven gear $B_2$</td>
<td>60</td>
</tr>
<tr>
<td>The rotate speed of drive gear (r/min)</td>
<td>215.1</td>
<td></td>
</tr>
<tr>
<td>The torque of drive gear (Nm)</td>
<td>96.4</td>
<td></td>
</tr>
<tr>
<td>Load factor</td>
<td>1.515</td>
<td></td>
</tr>
</tbody>
</table>

Reading stresses separately in these three situations, the results are in Table 2.

### Table 2. Analysis results

<table>
<thead>
<tr>
<th>Different conditions</th>
<th>Tooth contact stress/MPa</th>
<th>Root bending stress of drive gear/MPa</th>
<th>Root bending stress of driven gear/MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without modification</td>
<td>1053.02</td>
<td>214.66</td>
<td>189.42</td>
</tr>
<tr>
<td>Crowning modification</td>
<td>647.8</td>
<td>163.61</td>
<td>128.63</td>
</tr>
<tr>
<td>Helical modification</td>
<td>291.82</td>
<td>71.11</td>
<td>59.43</td>
</tr>
</tbody>
</table>

Because the axial deviation of the gear pair is large while the load is light, every stress value when the gear pair is without modification is much larger than the value when it is modified. In addition, comparing stress values when it is modified with general crowning modification and helical modification, it shows that helical modification is more suitable for the working condition in Table 1. And all stress values are smaller than values when using general crowning modification under this situation.

Furthermore, obtaining contour maps of contact stress in these three situations to explore the effect of helical modification on improvement of uneven load distribution, they are described respectively as Figures 4(a), 4(b) and 4(c). Figure 4(a) indicates that contact area is very small and located at one side of tooth when the gear pair without modification. Thus, it is necessary to conduct modification for the gear pair. And the contour map of Figure 4(c) compared to Figures 4(a) and 4(b), contact area obviously moves to tooth center, and contact stress decreased. That means helical modification can solve the issue of uneven load distribution.

![Nodal Solution](image-url)
Along the direction of tooth width, contact stress values can be gotten in these situations. Collecting and organizing these values, the graph is drawn as Figure 5. Comparing three curves in the graph, it illustrates that when the gear pair is modified with helical modification, the distribution of contact stress is more uniform and stress values are much smaller than others. And the figure indicates the advantage of helical modification intuitively, and the performance and carrying capacity can be improved by performing helical modification.
4.2 Fatigue analyzing of gear pair with helical modification

In order to make sure the tooth surface strength of gear, fatigue analysis of tooth surface contact is conducted for the gear pair with helical modification. The most dangerous position can be found from previous transient meshing analysis, and then the finite element model at this position is imported into Workbench software. Conducting static structural analysis for gear pair firstly, the input of $\sigma$-$N$ curve is shown as Figure 6 when setting material properties for modified gear pair.

![Figure 6. Curve of $\sigma$-$N$](image)

When the static analysis is finished, fatigue tool is added to the project, and safety factors of modified gear can be read. Especially, safety factors of contact area are shown in Figure 7. And the minimum is 1.2343, which is greater than 1. That means contact fatigue strength of modified tooth surface meets the requirements.

![Figure 7. Safety factors](image)

IV. CONCLUSION

As for straight spur gears with light load and large axial deviation, helical modification can solve the issue of uneven load distribution and improve carrying capacity dramatically compared to general crowning modification. Conducting transient meshing analysis for gear pair, analysis results show that contact area moves to tooth center and contact stress decreases obviously when gear pair is modified with helical modification. In addition, taking a pair of gears as an example, contact fatigue analysis was applied to the gear pair when it is at dangerous position. And result delicates that tooth surface strength can meet the requirement when gear pair is modified using helical modification.

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