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Analyze the influence of carburized layer thickness and assembly error on the reliability of thin-walled gear ring system based on ABAQUS

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ABSTRACT

Internal meshing, an innovative mechanical transmission mode that enjoys widespread application, high transmission accuracy, and compact structure, is frequently employed within planetary transmission mechanisms. However, the assembly process of these gears inevitably introduces various types of assembled errors. In this research paper, we utilize a parametric modeling technique for gears based on the Creo software to establish three-dimensional models of gears. Subsequently, we employ the ABAQUS software to analyze and solve finite element problems related to the different forms of assembled errors. Our objective is to investigate the impact of these errors on the stress and strain of gear components, particularly the thin-walled gear rings in transmission processes. Furthermore, we also evaluate the performance of these gear rings under varying carburized layer thicknesses. Through our comprehensive analysis and examination, we aim to provide valuable insights into optimizing internal meshing systems and enhancing their structural integrity and reliability.

Keywords: Thin walled gear ring, internal meshing, assembly error, carburized layer, finite element.

1. INTRODUCTION

Due to the assembly technology and assembly method, abnormal phenomena such as "one end contact" and the straightness deviation of the gear shaft (different shafts, misalignment), and the imbalance of the gear are usually caused during the assembly of the gear. When a pair of mutually meshing gear shafts are not parallel, only one end will contact in the tooth width direction, or the straightness deviation of the gear will occur, so that the load borne by the gear is not uniform in the tooth width direction, and the dynamic torque can not be transmitted smoothly[1]. Finally, uneven stress and strain will be generated, which may reduce the reliability of the gear and reduce its useful life of the gear.

In this academic paper, the focus is on analyzing the impact of different types of assembly errors on the performance of internal meshing gears. To begin with, we utilize ABAQUS software to solve a case without any assembled errors as a control group. This serves as a baseline for comparison with subsequent analyses that incorporate various forms of assembly errors. As part of the analysis, we examine the effects of carburization on the gear surfaces, which is a common technique used to increase their hardness, wear resistance, and fatigue strength. Specifically, we compare the performance of gear rings with varying depths of carburized layers. By doing so, we aim to gain a better understanding of how these factors contribute to the overall structural integrity and reliability of internal meshing systems. Through our comprehensive analysis and examination, we hope to provide valuable insights into optimizing assembly processes and enhancing the performance of internal meshing gears in various applications.

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2. ASSEMBLY ERROR TYPE

The assembly error of the thin-walled gear ring system mainly comes from the assembly process of the gear ring and planetary gear, and is also affected by the machining accuracy of the mating part[2]. The assembly error can be divided into two categories according to the axial relationship between the gear ring and the planetary gear, namely, the axis is parallel and the axis is not parallel.

In this study, the impact of assembly errors on the performance of internal meshing gears is investigated. To begin with, we categorize the assembly errors into two groups based on the axial relationship between the gear ring and the planetary gear. The first group involves an axis that is parallel to the planetary gear, while the second group involves an axis that is not parallel to the planetary gear. We find that the main factor contributing to the assembly error in the parallel axis category is the center distance error, which refers to the actual distance between the two axes being either larger or smaller than the theoretical distance. This error can have a significant impact on the performance of the gear ring, particularly in terms of its stress and strain levels. To further analyze these effects, we utilize ABAQUS software to simulate and compare different assembly error scenarios. Through our comprehensive analysis and examination, we aim to provide valuable insights into optimizing internal meshing systems and enhancing their structural integrity and reliability[3]. The assembly errors with nonparallel axes include the deflection angle around the X axis and the deflection angle around the Y axis (in this paper, the direction of the degree of freedom of rotation is the Z axis). The classification of assembly errors is shown in Fig. 1.

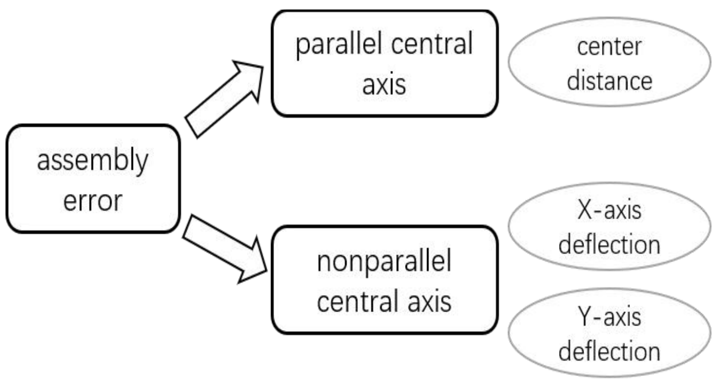

Figure 1. Type of Assembly Error

In Fig. 2 ~ Fig. 4, the meaning of error in the three-dimensional model is vividly shown.

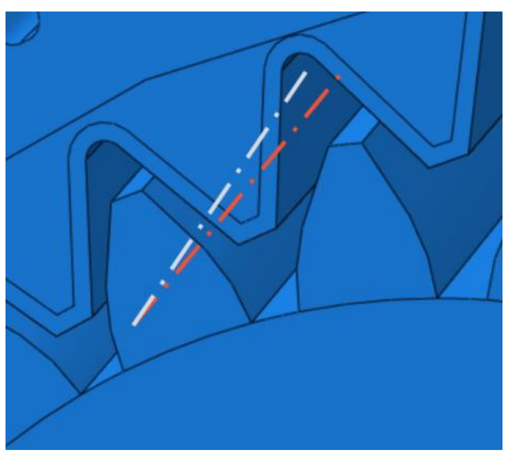

Figure 2. Deflection around the X axis

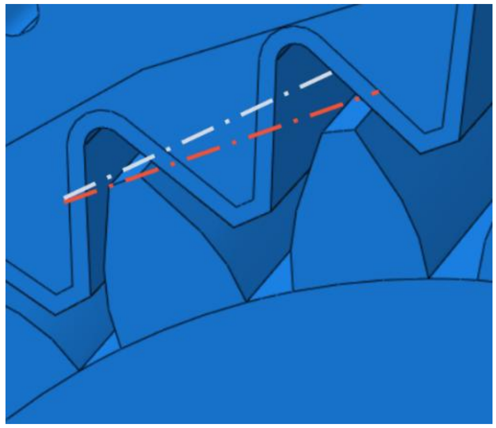

Figure 3. Deflection around the Y axis

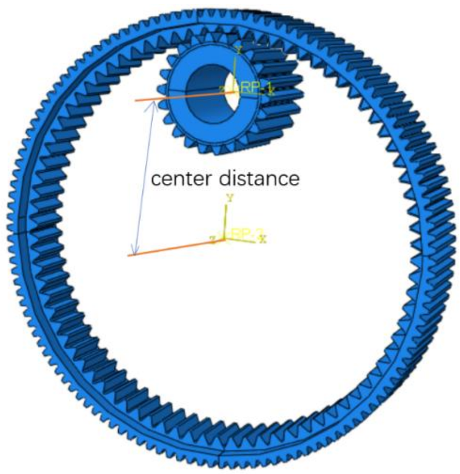

Figure 4. Deflection around the Y axis

3. CARBURIZED LAYER OF THE GEAR RING

Carburizing is a widely used surface chemical heat treatment process that dates back to ancient times. The process involves the infiltration of carbon elements into the surface of a metal, such as steel, to increase its carbon content. This results in the formation of a high-hardness surface layer and a low-carbon martensite core with good strength and toughness through quenching [4].

There are three types of carburizing schemes: solid carburizing, liquid carburizing, and gas carburizing. Solid carburizing involves the immersion of the part in a bath of carbonaceous materials, while liquid carburizing uses aqueous solutions containing carbon monoxide or hydrogen carbide. Gas carburizing, on the other hand, utilizes a gaseous mixture of carbon monoxide and nitrogen to infiltrate the surface of the part. Currently, gas carburizing is the most commonly used method in industry due to its efficiency and cost-effectiveness. However, solid carburizing remains an important alternative for certain applications where higher accuracy and control over the process are required. Regardless of the specific method employed, carburizing is an essential step in improving the properties of metals and ensuring their durability and reliability in various mechanical systems.

The carburized layer depth of the workpiece is generally selected according to the load of the workpiece. Generally, the carburized layer depth of the gear with bending fatigue fracture is taken as the lower limit[5], the carburized layer depth of the gear with contact fatigue damage is taken as the upper limit, and the carburized layer depth of the gear with large load is taken as the upper limit. The carburized layer depth of the workpiece is generally selected according to the load of the workpiece[6]. Generally, the carburized layer depth of the gear with bending fatigue fracture is taken as the lower limit, the carburized layer depth of the gear with contact fatigue damage is taken as the upper limit[7], and the carburized layer depth of the gear with large load is taken as the upper limit[8].

In the gear ring system studied in this paper, the reference value of the carburized layer on the surface of the gear ring is 1.05mm. This is the thickness of the control group in the experiment as well.

In ABAQUS software, separate carburized layers are cut out, and the unique material attribute data (density, Poisson's ratio, Young's modulus, etc.) of carburized layers are assigned[9]. Through different carburized layer thicknesses to carry out simulation experiments, and then get the effect of carburized layer thickness on the performance of thin-walled gear ring. In the three-dimensional model, the cut carburized layer is shown in Fig. 5.

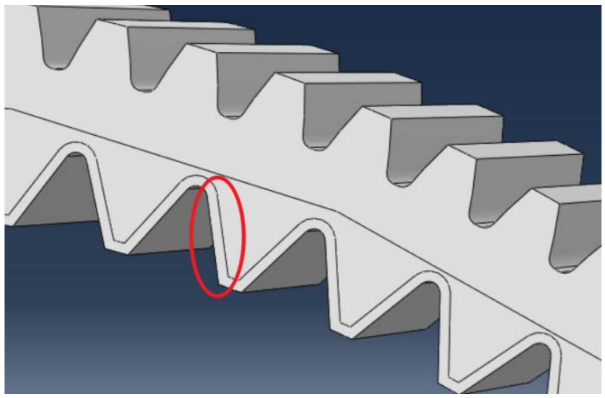

Figure 5. Carburized layer in 3D model

4. FINITE ELEMENT SIMULATION OF THE CONTROL GROUP

We have focused on examining the impact of carburized layer depth on the contact stress of thin-walled gear rings. To this end, we conducted several experiments with different carburized layer depths, with one experiment featuring a depth of 1.05mm. The results of these experiments are presented in Table 1, along with detailed descriptions of the experimental conditions used. It is important to note that all experiments were conducted using high-precision equipment and techniques to ensure accurate measurements of the contact stress. Additionally, each experiment was carefully controlled to minimize any potential sources of error or variability.

Table 1. Experimental conditions of the control group

Experimental parameters	**Numerical**
Carburized layer depth	1.05mm
Deflection angle about the x-axis	0.0°
Deflection angle about y-axis	0.0°
Center distance deviation	0mm
Speed	20r/s
Torque	3kN·m

The solution results of the thin-walled gear ring without assembly error are shown in Fig. 6 ~ Fig. 11, showing the assembly model of the gear ring, and the stress and strain of the short planetary gear and the gear ring respectively.

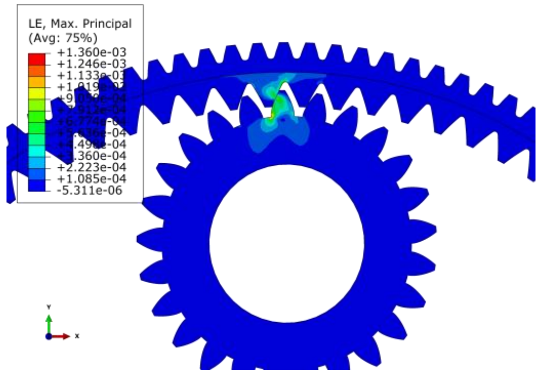

Figure 6. Contact strain cloud diagram of gear ring assembly model

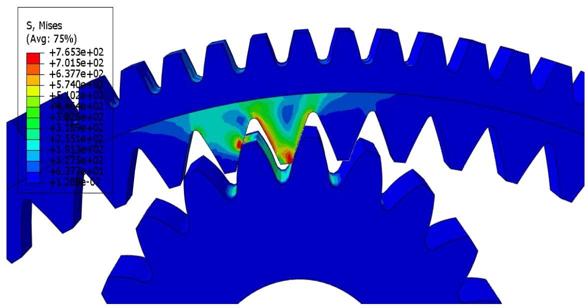

Figure 7. Contact strain cloud diagram of gear ring assembly model

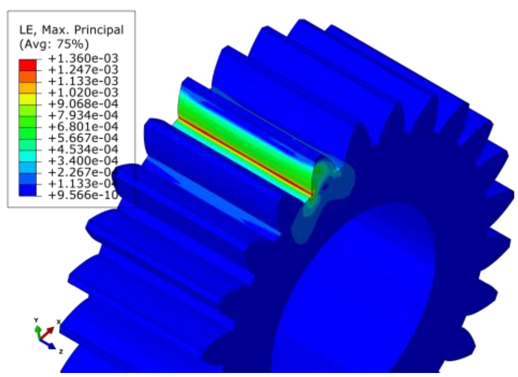

Figure 8. Cloud diagram of contact strain of short planetary gear

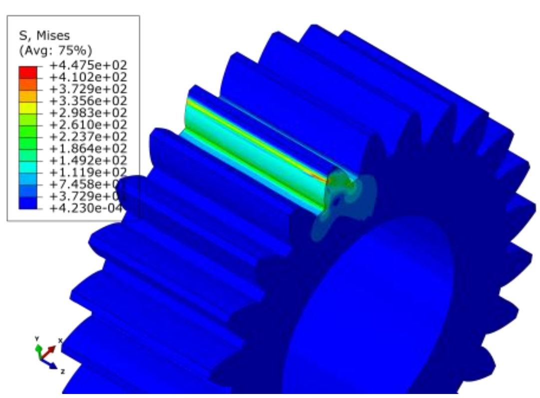

Figure 9. Cloud diagram of contact stress of short planetary gear

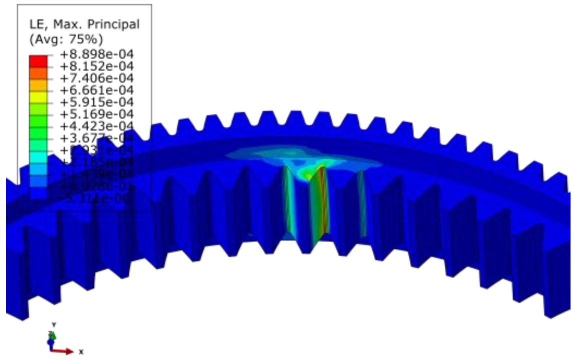

Figure 10. Cloud diagram of contact strain of gear ring

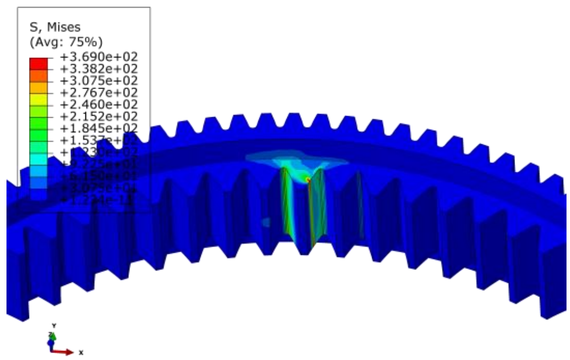

Figure 11. Cloud diagram of contact strain of gear ring

In addition, we also compared the maximum stress of the ring gear in the three directions of X, y and Z. Table 2 shows the overall combined stress and the stress results in each direction.

Table 2. Stress results in the direction of gear ring

Stress attribute	stress value
Maximum equivalent stress (M-Mises)	521MPa
Maximum tensile stress (X direction) S11	205.4MPa
Maximum compressive stress (X direction) S11	549.3MPa
Maximum tensile stress (Y direction) S22	149.4MPa
Maximum compressive stress (Y direction) S22	546.4MPa
Maximum tensile stress (Z direction) S33	380.7MPa
Maximum tensile stress (Z direction) S33	1187MPa

5. INFLUENCE OF CARBURIZED LAYER THICKNESS

In this part, we use different carburized layer thicknesses for finite element simulation to explore the influence of carburized layer thickness on the ring gear system. The carburized layer depth is 0.6 mm, 0.8 mm, 1.2 mm, 1.4 mm and 1.6 mm respectively. Other experimental conditions are the same as when there is no assembly error.

The contact stress of the thin-walled gear ring in different directions is calculated under different carburized layer depths as shown in Fig. 12. Proper assembly techniques played a crucial role in ensuring optimal performance of the ring gear system. Even small variations in the assembly process could result in significant differences in the stress distribution within the gear system and ultimately impact its reliability.

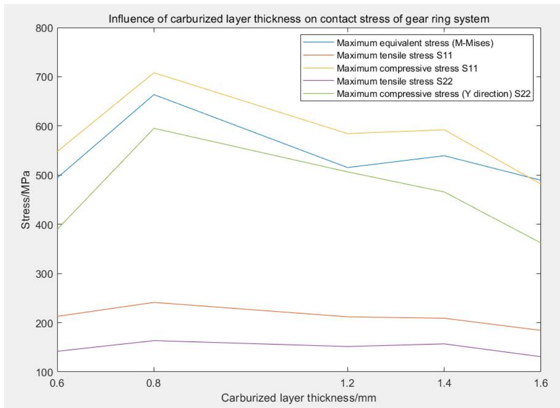

Figure 12. Effect of carburized layer depth on contact stress

It can be seen from the calculation results that the maximum tensile stress in the X direction and the maximum tensile stress in the Y direction are less sensitive to the carburized layer, while the maximum equivalent stress, the maximum tensile stress in the X direction and the maximum tensile stress in the Y direction are more sensitive to the carburized layer. The overall change trend of these five stresses is that they become larger first and then smaller with the deepening of the carburized layer thickness, and reach the maximum when the carburized layer thickness is about 0.8mm.

6. INFLUENCE OF ASSEMBLY ERROR

The present section delves into the impact of various axial plane inclinations and vertical axis plane inclinations on the contact stress of a ring gear system. To this end, we analyze the effects of these angles using advanced mathematical models and simulations. Our findings reveal that both axial and vertical plane inclinations can significantly alter the contact stress distribution within the ring gear system. Specifically, we observe that increasing the axial inclination leads to a greater concentration of contact stress at the edges of the gear teeth, while decreasing the vertical inclination results in a more even distribution of stress across the entire surface. These findings have important implications for optimizing the performance and reliability of ring gear systems in a range of industrial applications.

6.1 Deflection angle around X axis

The experiments were carried out with the inclination angles of 0.2 °, 0.4 °, 0.6 °, 0.8 °, and 1.0 ° around the x-axis, and other experimental conditions were the same as when there was no assembly error. The final solution results are shown in Figure 13.

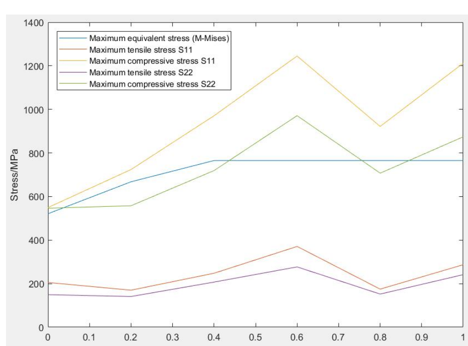

Figure 13. Influence of inclination angle around X axis on stress

It can be seen from the experimental data that changing the in-plane inclination angle has little effect on the contact stress of the thin-walled gear ring, and the maximum tensile stress and the maximum compressive stress in the X and Y directions show a trend of first rising, then falling, and then rising slightly.

6.2 Deflection angle around Y axis

The experiments were carried out with the inclination angles of 0°,0.2 °, 0.4 °, 0.6 °, 0.8 °around the y-axis, and other experimental conditions were the same as when there was no assembly error. The final solution results are shown in Figure 14.

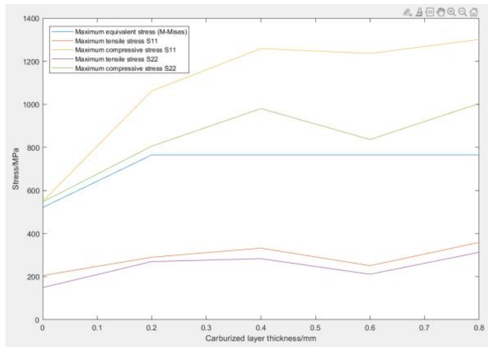

Figure 14. Influence of inclination angle around X axis on stress

It can be seen from the simulation results that with the increase of the inclination angle between the vertical axis planes, each stress value presents a concave shape change trend in the overall trend. Although it decreases at the angle of 0.6 °, each stress value is still larger than that of the control group.

6.3 Center distance

We calculated the center distance deviation of -0.2mm ~ 0.2mm, and the calculation results are shown in Fig. 15.

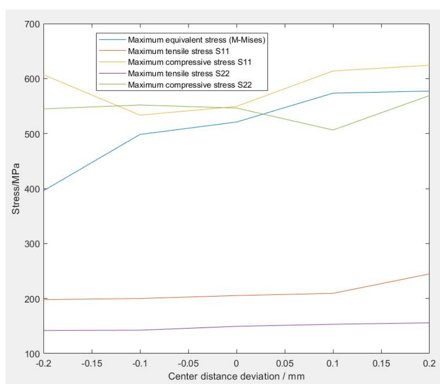

Figure 15. . Influence of inclination angle around X axis on stress

With the increase of the center-to-center distance of the ring gear system, the maximum equivalent stress shows an obvious upward trend[10]. The maximum tensile stress in X and Y directions is not sensitive to the center-to-center distance, and there is no obvious change after - 0.1mm. However, the compressive stress in these two directions is sensitive to the change in the center-to-center distance.

7. CONCLUSION

This paper aims to investigate the impact of carburized layer thickness and assembly error on the transmission of a ring gear system. To achieve this, the finite element method (FEM) was employed for analysis. The experimental results were compared with those obtained from a control group, which had different depths of carburized layers.

The results revealed that the overall stress change trend increased initially before reaching a peak value at about 0.8mm, after which it gradually decreased. This finding suggests that increasing the depth of carburized layers can improve the strength and durability of the gear system, but excessive depth may lead to an increase in stress levels beyond the system's capacity.

Furthermore, the study also highlighted the importance of proper assembly techniques in ensuring optimal transmission performance. Assembly errors, such as misalignment and improper lubrication, can significantly affect the stress distribution within the gear system and reduce its efficiency.

Overall, these findings provide valuable insights into optimizing the performance and reliability of ring gear systems by carefully controlling carburized layer thickness and implementing effective assembly procedures.

When comparing the assembly errors, the stress conditions under three different types of assembly errors were compared. The deflection angle around the X axis, the deflection angle around the Y axis and the center distance. It can be seen that the maximum stress will increase with the increase of the deflection angle. When the center distance is changed, the more pressing will lead to greater stress. At the same time, attention should be paid to the size of the error. If the error is large, the model will collapse and cannot mesh correctly.

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