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Parametric modeling and finite element simulation of gear ring system based on creo and ABAQUS

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ABSTRACT

Internal meshing is a commonly used mode of meshing between gears. In this paper, we focus on the parametric modeling method for spur gears in Creo 2.0 and how it can be used to design corresponding gear and gear ring systems. The Abaqus 2020 software was utilized to perform finite element simulation experiments on the internal gear-ring system under specified working conditions, allowing us to obtain detailed information on the stress and strain distribution within the system.The parametric modeling method used in this study involves the use of advanced mathematical algorithms to create a digital representation of the gear's geometry, including its teeth profile, root diameter, pitch diameter, and other critical parameters. This digital representation is then used to generate a virtual model of the gear and its associated components, such as the gear ring.By using the Abaqus 2020 software, we were able to simulate the internal meshing of the gear and its associated components under a range of different operating conditions, including high loads, high speeds, and high temperatures. These simulations allowed us to evaluate the performance of the internal gear-ring system under real-world conditions and identify any potential weaknesses or areas for improvement.

Keywords: Internal engagement, parametric modeling, finite element, simulation analysis, formatting.

1. INTRODUCTION

The gear transmission system garners immense recognition in the realm of mechanical transmission, owing to its compact structure, dependable operation, and consistent transmission ratio[1], thereby establishing itself as a pivotal mode of transmission. Amidst the myriad of gear meshing methods, internal meshing emerges as a widely adopted technique that shares numerous resemblances with external meshing transmission[2]. It is worth noting that internal meshing gear transmission exhibits noteworthy attributes, including stable operation, substantial mesh overlap, exceptional load-bearing capacity, and heightened transmission efficiency. Consequently, it finds extensive utilization in planetary transmission mechanisms. In order to enhance the efficiency of the design process, the implementation of Creo facilitates the parametric modeling of gears, effectively streamlining the creation and refinement of three-dimensional models[3].

2. PARAMETRIC MODELING METHOD OF GEARS

Parametric modeling, a model creation approach facilitated by modeling software, offers an interactive and expeditious solution. This methodology relies on encapsulated logic, which designates several user-input parameters. After receiving user inputs, the program conducts internal logic analysis and processing to yield the desired three-dimensional model. Fundamentally, parametric modeling leverages mathematical techniques to impose constraints on geometric attributes[4]. The strength of parametric modeling lies in its ability to accurately and efficiently generate diverse gear geometric models. For our purposes, the parametric modeling of gears is achieved through the utilization of Creo 2.0. In this context, we will elucidate the parametric modeling process by focusing on the internal gear ring as our exemplar.

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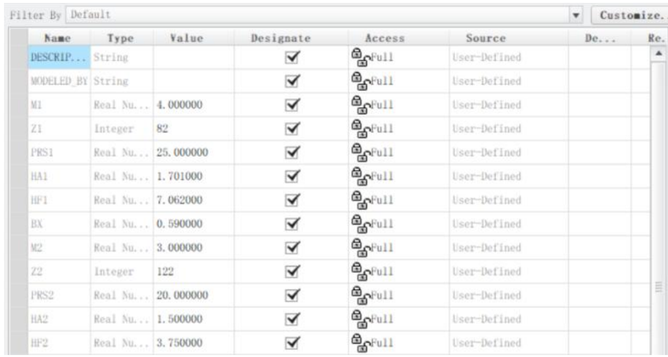
2.1 Setting parameters

The parametric modeling of the involute gear necessitates several key parameters, including the modulus, number of teeth, pressure angle, tooth crest height, tooth root height, and displacement coefficient[5]. In the tool menu bar, these variables can be defined under the "parameters" option, as depicted in Figure 1. By setting the appropriate values for each parameter, the software can accurately generate the desired gear model using the principles of parametric modeling.



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M1	Real Nu...	4.000000	✔	Full	User-Defined		
Z1	Integer	82	✔	Full	User-Defined		
PRS1	Real Nu...	25.000000	✔	Full	User-Defined		
HA1	Real Nu...	1.701000	✔	Full	User-Defined		
HF1	Real Nu...	7.062000	✔	Full	User-Defined		
BX	Real Nu...	0.590000	✔	Full	User-Defined		
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PRS2	Real Nu...	20.000000	✔	Full	User-Defined		
HA2	Real Nu...	1.500000	✔	Full	User-Defined		
HF2	Real Nu...	3.750000	✔	Full	User-Defined		

Figure 1. Main parameters of gear ring

2.2 Drawing parameter circles in sketches

In the sketch, a total of 9 circles, each varying in size, are depicted, incorporating both internal and external gears within the gear ring. Their geometric arrangement reveals a concentric circle configuration. By establishing the appropriate referencing relationship between the gear reference circle, the profile required for the involute gear can be created, as illustrated in Figure 2. This approach ensures the accuracy and precision of the gear model, aligning with the desired specifications and parameters for effective parametric modeling[6].

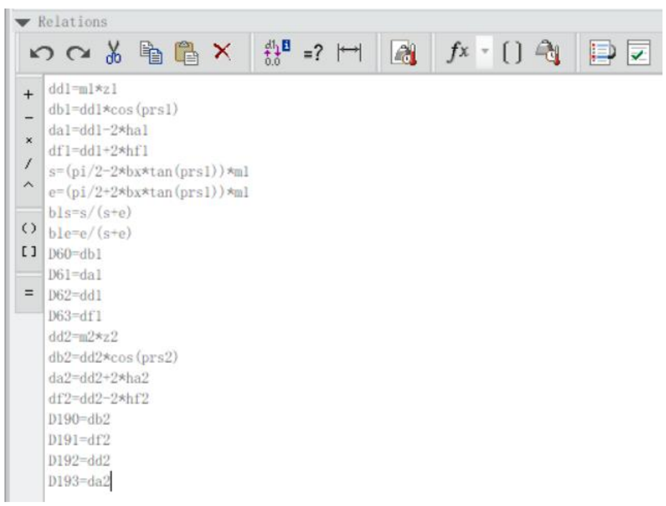


Figure 2. Geometric parameter circle of the gear ring

2.3 Ring gear solid model creation

The initial tooth is formed through the elongation of the feature, after which the first tooth slot is replicated, followed by the generation of all tooth slots through the employment of an array. The modification feature is then created through stretching and cutting processes. Ultimately, the resultant ring gear, depicted in Figure 3, is obtained. This series of steps enables the precise construction of the tooth geometry and facilitates the accurate formation of the final gear model[7].

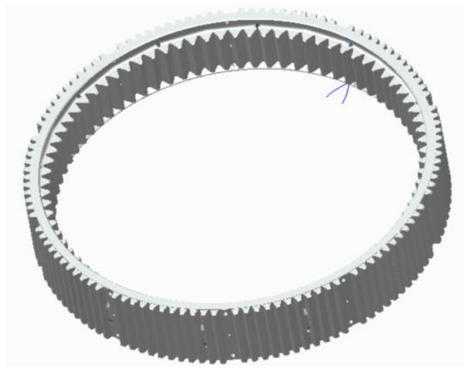


Figure 3. Geometric model of the gear ring

2.4 Drawing short planetary cylindrical gears

By using the parameter modeling method mentioned earlier, we can proficiently draw short planetary cylindrical gears, as shown in the figure below, and Figure 4 shows their appearance. This method ensures a systematic and accurate description of the complex details and geometric shapes of gears, thereby achieving seamless integration in larger mechanical components[8]. Adopting this method can achieve customization and adaptability during the design process, effectively analyzing and optimizing the performance characteristics of gears. This flexible modeling method provides engineers with more design freedom, enabling them to better meet the needs of specific applications and improve the efficiency and reliability of gear systems.

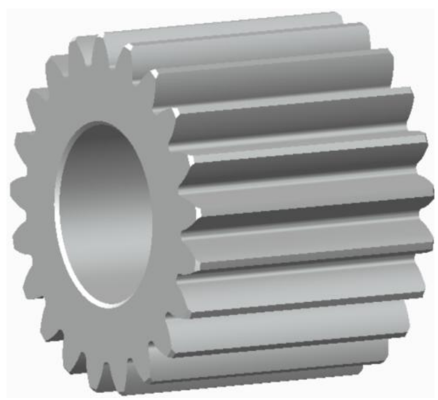


Figure 4. Geometric model of short planetary cylindrical gears

2.5 Saving files of gears

After successfully generating ring gears and gears, it is strongly recommended to save the model in ". x_t" format, which is a special file format provided by Creo 2.0. This format has excellent compatibility and ensures seamless integration when importing ABAQUS. Choosing this format can maintain the integrity of the complex features of the model and avoid any reduction or distortion in its contour. Therefore, using the ". x_t" format to save a model is a reliable method that ensures accurate data transmission and sharing between different software, while maintaining the accuracy and integrity of the model.

3. FINITE ELEMENT MODELING WITH ABAQUS

ABAQUS, a robust software package for engineering simulation based on the finite element method, is extensively employed to tackle a wide spectrum of engineering challenges, ranging from straightforward linear analyses to intricate nonlinear problems. The fundamental stages encompassed within the finite element solving process using ABAQUS encompass part creation, definition of material properties, mesh generation, part assembly, configuration of analysis steps, imposition of boundary conditions, submission of computations, and subsequent visualization and analysis of results. In the context of this study, ABAQUS is harnessed to carry out finite element analysis pertaining to gear engagement, empowering a meticulous evaluation of the gear's mechanical behavior and performance characteristics under varying operational conditions.

3.1 Importing 3D model of gear

In the initial step, the three-dimensional model of the ring gear and gear, which have been meticulously crafted using Creo software, is imported into the ABAQUS software environment. It is imperative to highlight that particular attention was devoted to surface manipulation of the gear ring, necessitating a distinct representation of the carburized layer, as visually depicted in Figure 5. This segregated rendering of the carburized layer ensures its comprehensive and accurate inclusion in subsequent analyses, crucial for capturing the nuanced mechanical behavior and response of the gear system under investigation.

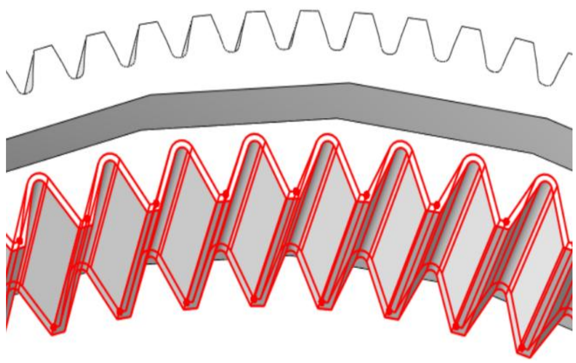
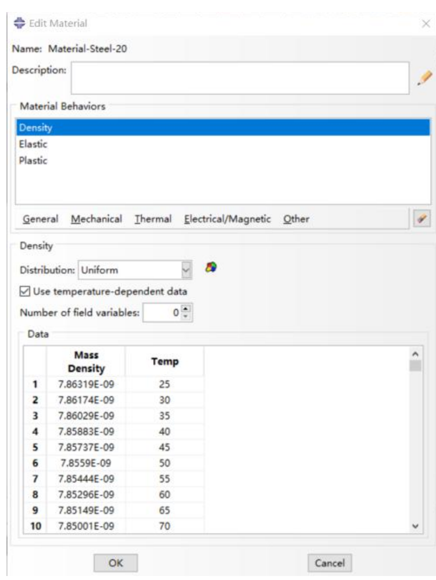


Figure 5. Carburized layer

3.2 Setting of material properties

The material properties of both the ring gear and gear are suitably defined in the following manner. Considering the outer surface of the gear ring, which undergoes carburization treatment, it becomes essential to allocate distinct material properties to the carburized layer. The material property values pertinent to the gear and carburized layer, encompassing parameters such as Poisson's ratio, density, Young's modulus, among others, are intrinsically influenced by temperature variations. The specific property values employed for the analysis are presented in a graphical format, denoted as Fig. 6. a) and Fig. 6. b), respectively, aptly illustrating the allocated attributes for both the gear and the carburized layer.



	Mass Density	Temp
1	7.86319E-09	25
2	7.86174E-09	30
3	7.86029E-09	35
4	7.85883E-09	40
5	7.85737E-09	45
6	7.8559E-09	50
7	7.85444E-09	55
8	7.85296E-09	60
9	7.85149E-09	65
10	7.85001E-09	70

Figure 6. a) Material properties of gears (only a part is shown)

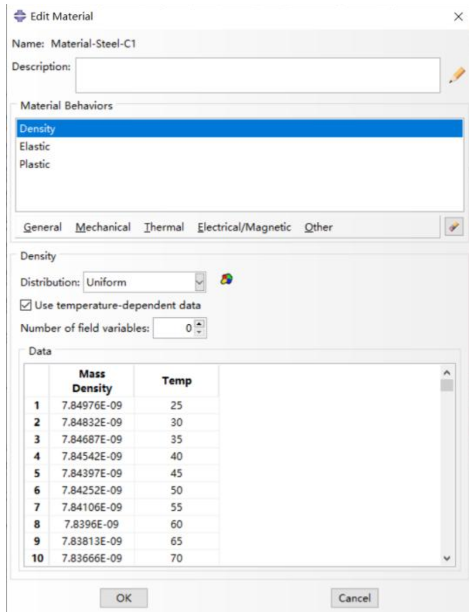


Figure 6. b) Material properties of carburized layer (only a part is shown)

3.3 Meshing of gear ring and gear

For finite element analysis, mesh generation is the most crucial step, and the quality of mesh generation directly affects the accuracy and speed of the solution[9]. Meshing has three steps: defining cell attributes (including real constants), defining grid attributes on the Geometric modeling, and meshing. Defining the attributes of the grid is mainly to define the shape and size of the cell. The unit size is basically defined on the line segment and can be divided by the number or length of the line segment. It can be declared immediately after the line segment is established, or one by one after the entire physical model is completed.

Owing to the intricate geometry and structure of gears, achieving a direct mesh can be challenging. Consequently, a two-step approach is employed, whereby the gear is initially partitioned into the gear body and gear teeth sections, delineated along the root circle. When considering the meshing contact between gears, the tooth region assumes unparalleled significance, with particular emphasis on the root segment as it is susceptible to stress concentration. Consequently, the meshing scheme devised for the tooth root necessitates a finer resolution, whereas other regions can be assigned coarser mesh sizes. This judicious combination of mesh densities not only guarantees solution accuracy, but also optimizes computational efficiency. In the case of the gear ring, finer meshing is employed specifically for the carburized layer. The culmination of the mesh generation process for both the ring gear and gear is visually presented in Fig. 7 and Fig. 8, showcasing the meticulous division of elements.

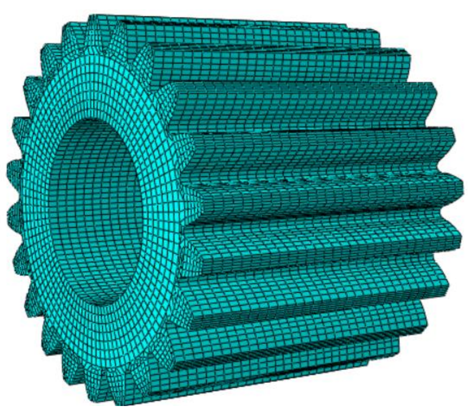


Figure 7. Meshing results of planetary gears

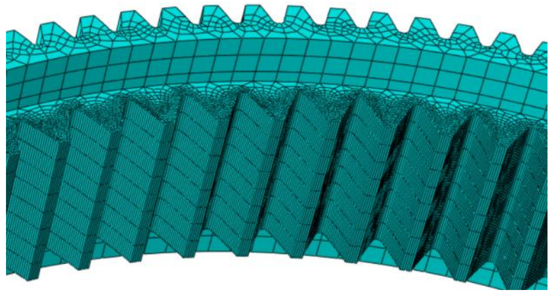


Figure 8. Mesh division result of gear ring

3.4 Assembling the ring gear system

The assembly process of the gear is performed within the assembly module of ABAQUS, adhering to the utilization of a standardized center distance for installation. The resulting assembly outcome, as obtained through ABAQUS, is visually depicted in Figure 9.

Figure 9. Assembled gear and gear ring

3.5 Defining analysis steps

Analyze intricate dynamics by generating a dynamic explicit general analysis step with a time increment of 0.05 s, taking into account geometric nonlinearity where the NL gocm option is enabled. To expedite the analysis process, minimize expenses, and optimize computational efficiency, a mass amplification factor of 10000 is implemented.

3.6 Defining contact

The distance existing between the two surfaces is referred to as the "gap," which, when reduced to zero, necessitates the imposition of a contact constraint within ABAQUS[10]. The contact problem formula does not impose any limitations on the magnitude of contact pressure that can be transmitted between the surfaces in contact. Upon the contact pressure reaching zero or becoming negative, the two surfaces separate, and the constraint is subsequently removed. This form of contact behavior is commonly referred to as "hard" contact. Henceforth, in our context, we define the contact attribute between two gear teeth as representative of hard contact. As an alternative, the contact relationship between the gear and the gear shaft can be substituted with a tie constraint.

3.7 Setting loads and boundary conditions

Regarding the load, this experiment applied a torque of $3000N \cdot m$ to the gear ring to simulate the load situation under actual working conditions. This torque value is determined based on system requirements and design parameters, and is crucial for the reliability and performance evaluation of the gear ring. By applying this load, we can analyze the stress and deformation of the gear ring under working conditions to verify its structural strength and usability.

Regarding boundary conditions, in order to accurately simulate the motion characteristics in the actual working environment, we set the gears and ring gears to only have rotational degrees of freedom in the Z direction. This means that gears and ring gears can rotate freely in the Z direction, but will be restricted in other directions. This boundary condition setting can better simulate the motion behavior in actual gear systems and provide accurate simulation results. The boundary conditions we set are shown in Figure 10, which are based on a comprehensive consideration of design requirements and system characteristics, aiming to ensure the accuracy and reliability of simulation results.

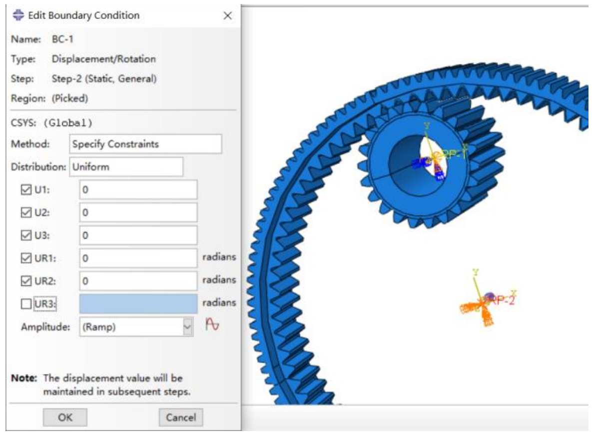


Figure 10. Boundary conditions

After completing the above tasks, we can submit the job for finite element solution calculation

4. FINITE ELEMENT ANALYSIS RESULTS

After using ABAQUS software for calculation, we can perform post-processing to observe the comprehensive stress distribution of the entire gear system. The visual representation of this stress distribution is shown in the figure below, and Figure 11 shows the detailed results. Through this visual chart, we can clearly understand the stress conditions of various parts in the gear system, thereby better evaluating the safety and stability of its structure.

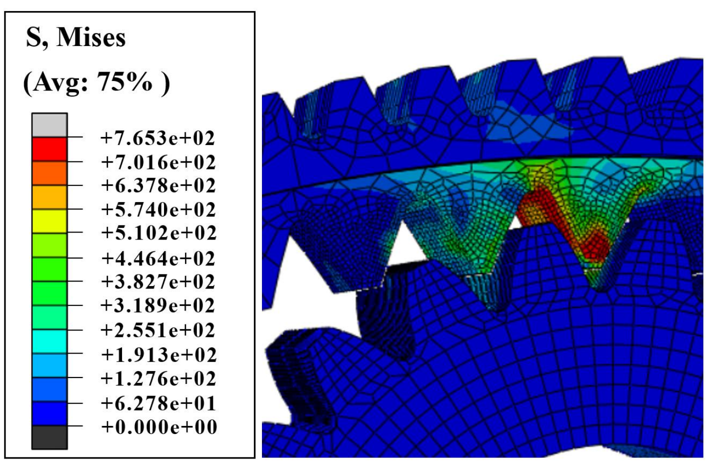


Figure 11. Overall Von Mises stress

The stress distribution at the root is a key indicator for evaluating the characteristics of gear transmission. The evaluation of the ring gear system found that the maximum stress reached 765.3MPa without considering eccentric load. In addition, this maximum stress peak was observed at the midpoint between the gear tooth surface and tooth root. This result indicates that in the gear transmission system, the root area bears the maximum stress load and requires special attention and optimization. By accurately evaluating and understanding these stress distribution characteristics, engineers can take corresponding design measures, such as increasing the strength of materials or optimizing the gear geometry, to improve the reliability and durability of the gear transmission system.

In Fig. 12 to 14, the stresses in the X, Y, and Z directions are individually showcased. Notably, the highest stress concentration is detected at the tooth root, whereas the stress magnitude at the meshing point is slightly lesser. Overall, these findings align closely with pertinent theoretical research in the field.

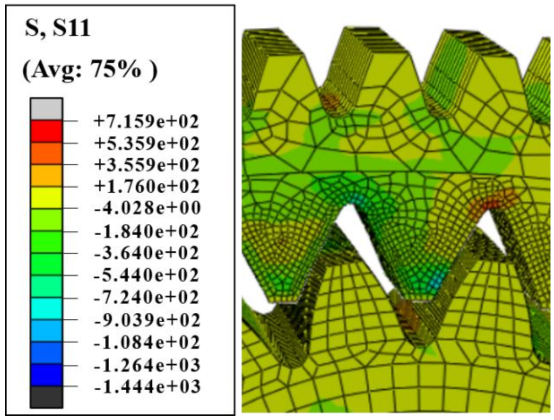


Figure 12. Stress results in S11 direction

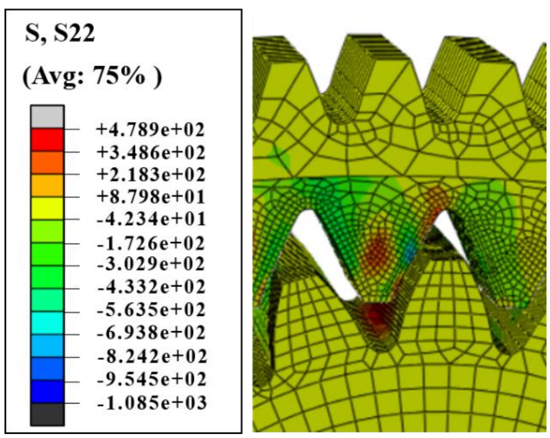


Figure 13. Stress results in S22 direction

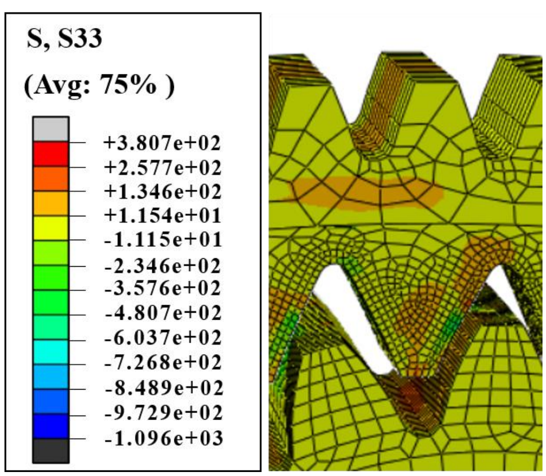


Figure 14. Stress results in S33 direction

5. CONCLUSION

This article provides a detailed introduction to the entire process of parameterized modeling of gears and gear rings using Creo software. By adopting parameterized modeling technology, the required 3D model can be easily generated by adjusting key parameters, greatly improving work efficiency. This method enables designers to quickly create gear and ring gear models of various specifications and types without the need to design every detail from scratch. By simply modifying parameters such as gear modulus, number of teeth, gear width, etc., designers can easily modify and optimize the model to meet different needs and design criteria.

In addition, by implementing the finite element analysis software ABAQUS, gear meshing contact can be simulated. The simulation results can clearly visualize the stress distribution in the gear system, providing important design references for engineers. It is worth noting that in a gear system, the highest stress is concentrated at the root of the tooth, while the stress at the meshing of the tooth surface is slightly higher. The comparative analysis of stress distribution shows that in the X, Y, and Z directions, the stress in the X direction is the highest, followed by the Y direction and finally the Z direction, while the stress in the Z direction is relatively small. These simulation results provide strong support for reliability analysis and valuable assistance for the optimization design of the gear ring system. Engineers can use these results to evaluate the structural strength of the gear system and make necessary improvements and adjustments based on actual needs to ensure that the system can operate safely and reliably under various working conditions.

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