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FINITE ELEMENT ANALYSIS AND LIGHTWEIGHT RESEARCH OF AN ELECTRIC VEHICLE DRIVE AXLE HOUSING

Guo Chao[1,2], Li Shouxin[1,2], Wang Yu[1,2], Wang Junjie[1,2], Yang Xuexin[1,2,] [0009-0001-8268-7410]*
[1]Department of Automotive Engineering, Hebei Institute of Mechanical and Electrical Technology
Xingtai 054000, Hebei, China
[2]New Energy Vehicle Lightweight Technology Research and Development Center of Xingtai,
Xingtai 054000, Hebei, China
**Corresponding author: Yang Xuexin, E-mails: xingtaixiaoyang@163.com*

Abstract - The drive axle housing of an electric truck is an important component to ensure the normal operation of the vehicle. The finite element analysis of drive axle housing is a necessary process in the design of drive axle housing. Through the research on the drive axle housing, the four typical force conditions of full load static condition, emergency braking condition, maximum tractive force condition and maximum lateral force condition are analyzed, and their strength is checked according to the national standard of "QC/T 533-2020 China Commercial Vehicle Drive Axle Assembly", so as to ensure the static strength of the drive axle. Through the modal analysis of the drive axle housing, it is ensured that the drive axle housing will not be damaged due to resonance problems during use. Finally, in the requirements of green environmental protection performance, the drive axle housing lightweight research was carried out on the drive axle housing, and through research optimization, the mass of the drive axle housing was reduced by 16.3%, saving a lot of materials. At the same time, the strength performance of the drive axle was also improved. The results show that the finite element analysis of drive axle housing is an important method to design high-quality drive axle housing. Lightweight research can not only reduce the waste of materials, but also improve the structure of the drive axle and improve its performance.

Keywords: Drive axle housing, Finite element method, Lightweight research, Strength check, Modal analysis, Structural optimization.

1. Introduction

The drive axle of an electric vehicle is an important part of the automobile parts assembly, which not only bears the load from the ground under various working conditions, but also is an important connection and force transmission part in the car. The performance of the drive axle is directly related to the vehicle's service life and is crucial for the vehicle's driving comfort, safety, and smoothness [1, 2]. In recent years, with the improvement of automobile safety performance and energy saving and environmental protection performance, the requirements for the drive axle are becoming higher and higher, so it is very important to optimize the performance of the drive axle [3].

The driving axle is subjected to more complex load conditions during use. Generally speaking, the strength of its typical working conditions is mainly analyzed according to the requirements of national standards, so as to ensure the safety performance of the driving axle [4]. However, even if the same method is adopted to calculate the safety performance of the drive axle, although the strength performance of the drive axle can be guaranteed, the designed drive axle structure has a large weight and does not fully meet the performance requirements of green protection [5-7].

During vehicle driving, the drive axle is subjected to various impact loads from the road surface, so it is necessary to check the drive axle's static strength [8]. Due to the influence of random vibration and forced pavement vibration, modal analysis is needed to avoid resonance [9, 10].

Studying the lightweight of the drive axle is an important research direction for improving the current drive axle performance [11, 12]. There are many lightweight research methods for drive axle, mainly including response surface method, multi-objective optimization algorithm, topology

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optimization, etc. [13, 14]. In order to ensure the safe performance of a certain type of electric truck's drive axle, the modified drive axle needs strength checks and finite element analysis. At the same time, in order to improve the performance of the drive axle, carrying out lightweight research on the drive axle can further optimize the performance of the drive axle. This research can provide research value for the design of drive axle housing.

2. Drive Axle Finite Element Modelling

2.1 Drive Axle Housing Modeling

According to the specific electric truck model, the corresponding drive axle model and the material names of each part are shown in Figure 1, and the material parameters are shown in Table 1. In the drive axle housing, the total length of the drive axle is 1620 mm, the length of the half - axle is 510 mm, the center - to - center distance between the left and right leaf spring seats is 1140 mm, the size of the flange plates at both ends is 82 mm, the inner diameter of the sleeve is 63 mm, the diameter of the reducer housing is 200 mm, and the axle load is 10,000 N.

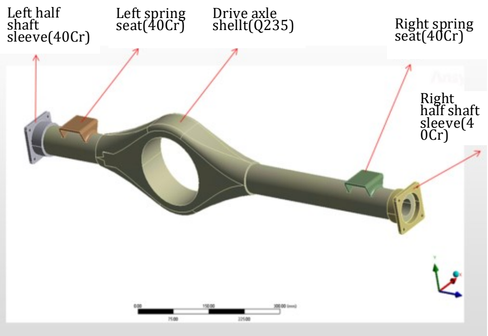


Figure 1: The 3D model and material type of drive axle

Table 1. Material parameter information

Material name	Density (kg/m^3)	Elastic modulus (GPa)	Poisson's ratio	Tensile strength (Mpa)	Yield strength (Mpa)
40Cr	7.85e3	210	0.3	980	785
Q235	7.8e3	200	0.29	400	235

The three-dimensional model of the drive axle was meshed by automatic mesh division method. The type of mesh unit was tetrahedron, and the obtained mesh model file is shown in Figure 2. Among them, the mesh size is 5mm, and there are 333,800 units with 589,713 nodes.

Figure 2: Mesh model of drive axle

After that, the finite element simulation analysis of the drive axle is carried out. According to the actual installation conditions, considering that both ends of the drive axle are connected to the half-shaft, the bushing tubes at both ends of the drive axle are set as fixed constraints.

3. Drive Axle Finite Element Analysis

3.1 Static Analysis of Drive Axle Housing

Full Load Static Condition

In the analysis process, the wheel force of the drive axle under full load static condition is calculated. The force on each wheel is 20000N, and the set constraints and load conditions are shown in Figure 3, finally, the static analysis results are shown in Figure 4.

Figure 3: Load and constraint under full load statics

Under this condition, the maximum deformation is located in the center of the axle housing near the right spring seat, and the shape variable is 1.4648mm. The "Evaluation Index of Automobile Drive axle housing bench Test" formulated by the national standard stipulates that the maximum allowable deformation per meter wheel base under full load condition is 1.5mm.

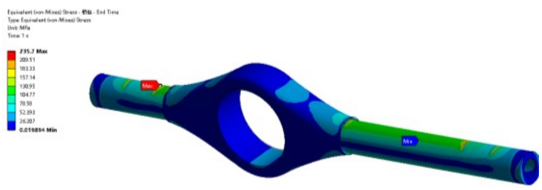


Figure 4: Stress distribution nephogram of axle housing

As shown in Figure 5, under this working condition, the maximum equivalent stress is located on the axle housing connected to the left and right spring seats, and the maximum equivalent stress is 235.7 MPa, which is close to the yield strength of the material used, Q235, at 235 MPa, and less than its lowest tensile strength of 400 MPa.

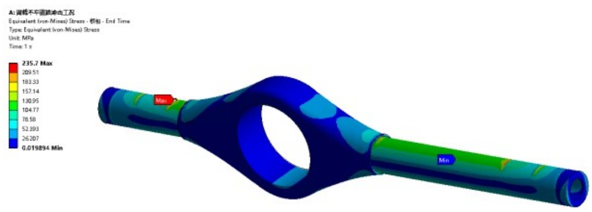


Figure 5: Stress distribution nephogram of axle housing

Maximum Traction Condition

When the vehicle's driving gear is in the first gear, the vehicle receives the maximum traction force, and the force condition of the vehicle under this working condition is relatively harsh. The calculated load and constraint conditions of the vehicle under this working condition are shown in Figure 6.

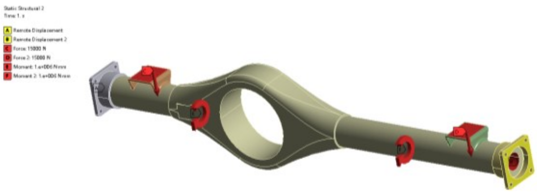


Figure 6: Load and constraints under maximum traction condition

The force diagram of the drive axle housing under this working condition is shown in Figure 7. Under this condition, the maximum deformation is located at the place deviating from the center of the axle housing near the right spring seat, and the shape variable is 1.1597 mm, which is less than the maximum deformation value of 1.5 mm formulated by the national standard.

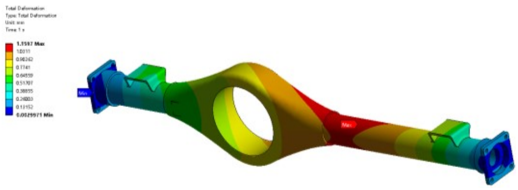


Figure 7: Deformation nephogram under maximum traction force

As shown in Figure 8, under this working condition, the maximum equivalent stress is located on the axle housing connected to the left and right spring seats, and the maximum equivalent stress is 178.24 MPa, which is less than the yield strength of the material Q235 used, which is 235 MPa.

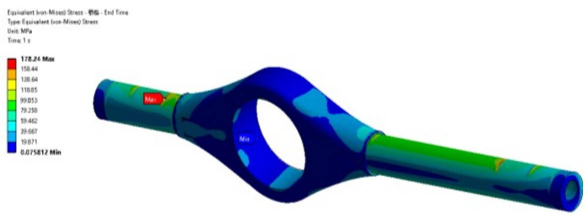


Figure 8: Stress nephogram under maximum traction force

Emergency Braking Condition

Under this condition, the ideal driving state is considered, that is, the car travels in a typical straight path. At this time, the car is subjected to the vertical reaction of the left and right wheels of the rear drive axle, and the tangential braking force and braking torque given by the ground in the opposite direction of the car. The constraints and loads of the drive axle under this working condition are presented in Figure 9.

Figure 9: Constraint and load under emergency braking condition

As shown in Figure 10, under this working condition, the maximum deformation is located at the place deviating from the center of the axle housing and close to the right spring seat, and the shape variable is 1.0757mm, which is less than the maximum deformation value of 1.5mm established by the national standard.

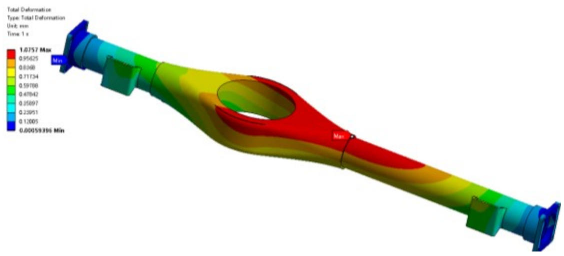


Figure 10: Deformation nephogram under emergency braking condition

As shown in Figure 11, under this working condition, due to the relatively large torque applied, the maximum equivalent stress is located on the axle housing connected to the left half shaft sleeve, and the stress value is 354.02 MPa, which exceeds the yield strength of the material Q235, but does not reach the tensile strength of the material.

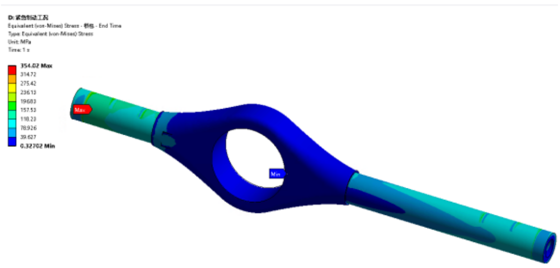


Figure 11: Stress nephogram under emergency braking condition

The Biggest Lateral Force Condition

When the fully loaded car turns at high speed, it will produce a very large centrifugal force at the center of mass of the car, and the ground will also give the wheel an opposite side force. If the car is in a critical state of sideslip, the side force will reach the maximum. To simulate the limit state of this condition, all the load of the drive axle is borne by the wheel on the side of the slip direction.

The constraints and force conditions of the vehicle drive axle under this working condition are shown in Figure 12.

Figure 12: Constraint and load under the biggest lateral force

As shown in Figure 13, under this working condition, the maximum deformation is located at the right end face of the axle housing connected to the right half axle sleeve, and the maximum shape variable is 2.1859 mm. Due to the special force in this working condition, in practice, part of the force acting on the axle housing under this working condition should be shared by other structures, so the actual force will not reach this value. If the structure size of the axle housing is increased, the mass of the axle housing will be too large, and the design cost is too high, so the value is considered to be within the acceptable range.

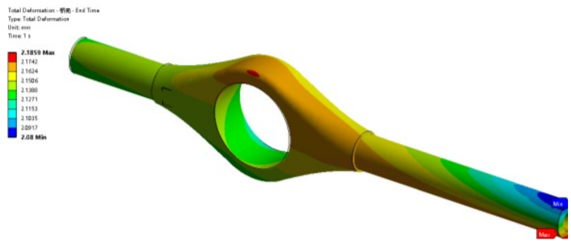


Figure 13: Deformation nephogram under lateral force condition

As shown in Figure 14, under this working condition, the maximum equivalent stress is located at the left end face of the axle housing connected to the left half axle sleeve, and its maximum value is 223.27 MPa, which does not exceed the yield strength of the used material Q235.

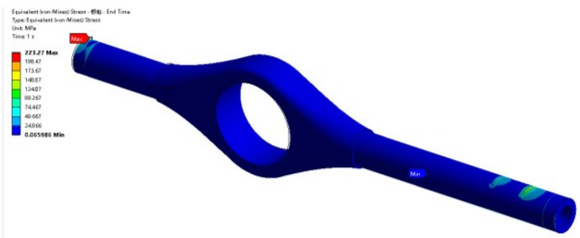


Figure 14: Stress nephogram under largest lateral force condition

Through the above analysis, it is considered that the designed drive axle meets the static requirements.

3.2 Modal Analysis of Driving Axle Housing

In order to further analyze the force condition of the drive axle housing and to analyze whether it resonates due to usage problems during use, it is necessary to carry out modal analysis of the drive axle housing to avoid the resonance problem by analyzing the low order natural frequency of the drive axle housing. Under the same constraint conditions, the first 10 natural frequencies of the drive axle are obtained, as shown in Table 2.

Table 2: The first ten natural frequencies of Drive axle housing

Number orders	Natural frequency (Hz)	Number orders	Natural frequency (Hz)
1	5.9e-2	6	681.32
2	0.22	7	725.47
3	245.2	8	1389.2
4	338.33	9	1518.4
5	589.3	10	1796

When the vehicle is driving on the actual road surface, the impact load frequency of the road surface is mostly in the range of 10 - 20 Hz, which is significantly different from the natural frequency shown in Table 2. Therefore, it is believed that the drive axle housing will not cause resonance damage due to the impact load of the road surface, which meets the design requirements.

4. Research on Lightweight of Drive Axle Housing

From the above analysis, it can be seen that the safety margin of the drive axle housing is high. In order to further optimize the performance of the drive axle housing, using lightweight research methods to optimize the quality of the drive axle housing can not only save vehicle energy consumption but also reduce the waste of materials and improve economy.

In the process of lightweight research, the lightweight research of the drive axle housing is realized by changing the inner diameter of the axle casing and the thickness of the leaf spring seat. The inner diameter of the drive axle housing is 120mm $\leq P_1 \leq$ 180mm, and the thickness of the leaf spring seat is $0 < P_2 \leq$ 1mm. The optimization objective is the mass P_3 of the drive axle housing, the constraint condition is the maximum deformation P_4 of the drive axle housing, which is required to be less than 1mm, and the equivalent stress of the axle package is P5 ≤ 200Mpa. The screening optimization algorithm is used to obtain the minimum mass of the drive axle housing. The calculation results of the optimized analysis sample and the change trend of the progress are shown in Figure 15 under certain impact conditions.

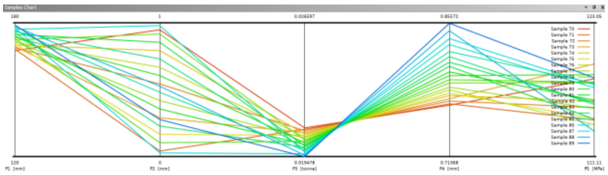
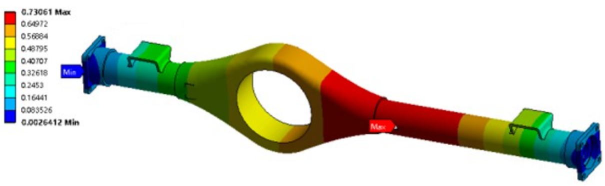


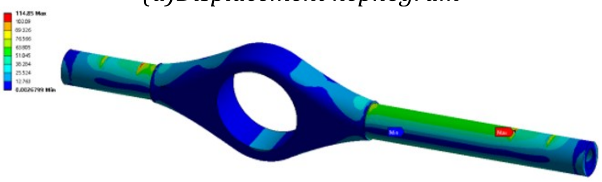
Figure 15: Impact optimization analysis process of drive axle housing

Finally, in the results recommended by the optimization analysis, when the inner diameter of the axle housing is 179.1mm and the thickness of both the left and right spring seats is increased by 0.278mm, the weight of the axle housing is the lightest, and the maximum shape variable and maximum equivalent stress of the axle housing are relatively small, so this set of optimization parameters is selected.

The finite element model established for the reconstruction of the optimized drive axle housing was analyzed. The maximum tractive force working condition was taken as an example for analysis. The optimized displacement and stress nephogram of the drive axle under the same load were shown in Figure 16.



(a)Displacement nephogram



(b) Stress nephogram

Figure 16: Displacement(a) and stress(b) nephogram of the optimized drive axle shell

As can be seen from Figure 16, the peak displacement and stress of the drive axle housing are significantly reduced after optimization, which not only realizes the lightweight of the drive axle housing, but also significantly improves its strength performance. Compared with the results in Table 3, it can be seen that the quality and mechanical properties of the optimized rear drive axle are significantly improved.

Table 3: Performance comparison before and after optimization

Name	Mass/kg	Displacement/ mm	Stress/MPa
Before	2328	1.46	235.7
After	1947	0.73	114.8

After optimization, the maximum equivalent stress of the axle housing is less than the yield strength of Q235, and the displacement value is less than the maximum deformation per meter under full load condition stipulated by the national standard, which is 1.5mm/m, which is in line with the standard. At the same time, the quality of the drive axle housing is significantly reduced, saving materials. At the same time, compared with Figure 8, the mechanical properties of the drive axle housing show that the maximum stress is about 114MPa, and the stress conditions of the drive axle are significantly improved. Therefore, it is considered that the deformation under the condition of maximum lateral force will also be reduced, which basically meets the requirements of safe use.

Due to the great change in the quality of the optimized drive axle housing, its natural frequency changes. Therefore, the modal analysis of the optimized drive axle housing is carried out again, and the first ten natural frequencies obtained are shown in Table 4 below.

Table 4: The first ten natural frequencies of optimized drive axle housing

Number orders	Natural frequency (Hz)	Number orders	Natural frequency (Hz)
1	4.8e-2	6	653.32
2	0.27	7	716.47
3	155.2	8	1105.2
4	281.33	9	1238.4
5	385.3	10	1896.5

The analysis shows that the natural frequency of the drive axle is a large value. In the form of an electric truck, the road excitation is usually a relatively low frequency incentive (10-20Hz), so it is believed that the drive axle housing will not produce obvious resonance phenomenon, which further ensures the safety performance of the drive axle housing.

Through the analysis, it can be seen that the statics performance of the drive axle housing can be improved while the lightweight research is realized. The research not only ensures the static performance of the transaxle, but also avoids the damage caused by resonance during the use of the transaxle.

5. Conclusions

The finite element analysis is carried out on the stress state of the drive axle housing under four typical working conditions. The finite element analysis results show that the maximum stress and strain of the drive axle housing meet the requirements of electric trucks and ensure the static performance of the drive axle housing.

Through modal analysis, it can be seen that the first 10 natural frequencies of the drive axle housing will not cause resonance problems due to normal driving, and the designed drive axle housing will basically not cause resonance damage during use, ensuring the dynamic performance of the drive axle housing.

In order to further optimize the performance of the drive axle, lightweight research has been carried out. By setting optimization objectives and parameters, the quality of the optimized drive axle housing is reduced by 16.3%, while the performance of the drive axle housing is improved, and a good optimization effect is achieved, which greatly improves the design quality of the drive axle housing.

Finite element method is an effective method to check and optimize the performance of the drive axle housing. Among many optimization methods, the finite element method has the advantages of low cost, high accuracy and convenient calculation, which is an important way to optimize the design of drive axle housing.

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