Strength Analysis and Research of one Touring Car Frame

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Abstract. In order to evaluate the static strength and reliability of touring car frame structure, based on the finite element theory and the simplified model, this paper establishes the finite element model to numerically simulate the static strength reliability of the structure under four common working conditions of bending, torsion, braking and turning. It analyses its maximum stress under the limit load, and finds out the weak area of the structure. The corresponding structural optimization scheme is proposed, which largely replaces the physical prototype verification process in the transmission design, greatly reduces the product R & D cycle, and provides theoretical support for the structural optimization of the whole vehicle.

1. Introduction
With the continuous improvement of people's living standards, as a passenger special vehicle integrating leisure, entertainment and life tourism, the application scope of touring car is also expanding. Its power adequacy, safety and reliability, good fuel economy, emission and cost performance need to be comprehensively considered in design and use. Therefore, in order to improve the safety in the use process of touring car and improve the stability in the driving process, it is necessary to analyze the frame structure of touring car, so as to provide theoretical support for the subsequent reasonable design of body, model and carriage, so as to comprehensively improve its safety performance, stability performance and green energy-saving design [1][2].

In this paper, the frame of a touring car is taken as the research object, and the static analysis is carried out in combination with the characteristics of daily use. On the basis of structural simplification, the stress of the touring car under bending, torsion, braking and turning is simulated by using the limit condition method. According to the analysis results, the strength of the frame is determined, and the weak position and strength rich part of the structure are found out. It provides theoretical guidance for subsequent structural modification, optimization and lightweight design.

2. Finite element analysis theory
Statics studies the simplification of force system and the equilibrium conditions that an object should meet under the action of force. The so-called frame static analysis is to apply different working condition loads to the frame, calculate the stress and strain of the frame under different working condition loads, so as to verify the stiffness and strength of the frame.

There are many kinds of working conditions when the vehicle is actually driving on different roads, and the load effect is also very complex. In this paper, the maximum deflection of girder section under bending condition is calculated by using the superposition principle. When the material obeys Hooke's law and the bending deformation is very small, the differential equation of the deflection contouring care can be calculated and expressed by Formula 1.
When several loads are acting on the beam at the same time, because equation (1) is a linear equation, the bending moment of the beam can be calculated by superposition method, which is \( M_1(x) \), deflection \( v_1 \). The differential equation of deflection cutouring care at this time is expressed by formula 2.

\[
\frac{d^2v}{dx^2} = \frac{M}{EI}
\]  

(1)

When the other load acts alone, the bending moment of the beam on any cross section is \( M_2(x) \), deflection \( v_2 \). Similarly:

\[
Elv_1 = M_1(x)
\]  

(2)

The two loads act simultaneously. If the bending moment is \( M(x) \) and the deflection is \( v \), the following can be obtained.

\[
ELv = M(x)
\]  

(4)

In the case of small deflection, that is, the bending deformation is very small, the bending moment can be calculated by using the size before deformation. At this time, the bending moment of the two loads acting at the same time is equal to the superposition of the bending moments acting separately.

\[
Elv_1 + Elv_2 = Elv
\]  

(5)

\( v_1 + v_2 \) is equal to the deflection \( v \) under the joint action of two loads. This result can be applied to the case of more than two loads. As long as the deformation of each load acting alone is obtained, and then superimposed, the deformation of these loads acting together can be obtained. This is the superposition principle for calculating bending deformation.

3. Establishment of finite element model of carriage

3.1 Simplification of frame structure

According to the requirements of analysis, the model is processed into geometric elements required for meshing in 3D software. When establishing the geometric model of frame finite element analysis, only the important parts of the structure concerned in this analysis are established, and the non-important parts are ignored or simplified [3-5].

The frame is a spatial steel frame structure composed of rectangular steel tubes by welding and other means. The geometric treatment is carried out by extracting the middle surface. The resulting geometric analysis model is shown in Figure 1.

![three-dimensional geometric analysis model of a touring car frame](image)

Figure 1. three-dimensional geometric analysis model of a touring car frame

3.2 Finite element mesh generation of frame structure

The touring car frame is welded by rectangular tubes with various sections and steel plates. Because the section size of these components is very small relative to the length of the components, it is suitable to be discretized by plate and shell elements, and the welding between components is simulated by shell elements. The model mesh is composed of a large number of quadrilateral shell elements and a small number of triangular elements. Regular quadrilateral elements shall be used as much as possible in the areas with simple structure and relatively heavy weight, and an appropriate number of triangular elements shall be properly arranged in the places with complex connections. The slope, Jacobian matrix, length ratio, warpage, maximum angle, minimum angle and other parameters of the divided element
mesh meet the calculation requirements. The average size of the grid of the structure is 10mm. The model has 920101 elements and 864513 element nodes, including 971329 quadrilateral shell elements and 48740 triangular elements. The established finite element model is shown in Figure 2.

![Figure 2. element model of touring car frame](image)

### 3.3 Material properties

Material properties include elastic modulus, shear modulus, density, etc. Different values can be given to material properties according to the actual situation. The material of the touring car frame studied in this paper is Q235 anisotropic square steel pipe and steel plate. Its elastic modulus $E$ is $2.1 \times 10^9$ MPa. Poisson's ratio $\mu$ is 0.3. Density $\rho$ is $7.85 \times 10^{-9} \text{t/mm}^3$. Yield strength is 235MPa. Tensile strength is from 370MPa to 500MPa.

### 3.4 Analysis condition

The vehicle is subjected to different forms of loads during driving, and four kinds of loads, such as bending load, torsional load, lateral load and longitudinal load, are the main loads. The equipment and goods loaded on the vehicle will produce vertical downward gravity due to their own mass. This gravity load acting on the vehicle is called bending load. The road surface on which the vehicle travels daily has a certain unevenness, and there is an asymmetric support during driving, which produces torsional load on the vehicle. When analyzing this situation, we usually choose to suspend a wheel to simulate the analysis. When the car turns during driving, there will be centrifugal force to produce lateral load. When accelerating and braking, the vehicle produces longitudinal load due to the action of inertial force.

The driving test procedure for automobile product type reliability stipulates that the sample vehicle must drive a certain mileage at a certain speed on various roads, which is mainly divided into four typical working conditions: bending, torsion, emergency braking and emergency turning on high-speed roads, general roads and contouring cared roads.

In order to apply loads and constraints, the global rectangular coordinate system is defined first. In this paper, the forward direction of the vehicle is taken as the x-axis; The left side of the driver is the y-axis, and the z-axis is determined according to the right-hand law, vertical to the ground.

### 4. Strength analysis

#### 4.1 Bending condition

The bending condition is mainly used to simulate the state of the vehicle running in a straight line at a constant speed on a good road when the vehicle is fully loaded and all wheels are on the ground. This condition is one of the basic conditions that often occur in vehicle driving. Under the working condition, the vertical symmetrical load acts on the frame, and the longitudinal bending deformation is the main deformation form. Under this condition, the load on the whole frame is mainly composed of structural weight and cargo weight. The stress calculation results of the frame under this working condition are obtained, as shown in Figure 3.
It can be seen from the analysis results in Figure 3 that under the bending condition of full load, the stress of the touring car frame is mainly concentrated on the support pipe of the centralized prevention system, and its maximum stress is between 650 and 680MPa. The stress in other areas is small, and the maximum stress is below 100MPa.

4.2 Torsional working condition

When the touring car is driving on a bad road, the wheels may be lifted and twisted when passing through the uneven road, resulting in the eight wheels not in the same plane. At this time, the touring car is in the working condition of one wheel lifting, and the body is twisted and deformed. When passing through the bad road at low speed, the touring car is easy to suffer the most severe torsional working condition. Due to the low speed, the dynamic load under this torsional working condition changes slowly with time, so the inertial load is very small. The stress calculation results of the frame under this working condition are shown in Figure 4.

It can be seen from the analysis results in Figure 4 that under the torsional condition, the stress of the touring car frame is also mainly concentrated on the support pipe of the centralized prevention system, with the maximum stress between 650 and 680MPa and the maximum stress in other areas below 100MPa.

4.3 Braking condition

If the vehicle adopts emergency braking, inertial force will be generated due to the action of inertia. Therefore, in the analysis of braking conditions, it is necessary to increase the inertial force load and deal with the load under braking conditions. The ground braking force can be simplified to the action of concentrated force through equivalent calculation on the nodes of the model. If the maximum adhesion coefficient of the pavement is set to 0.7, the inertial force load is $0.7 \times 9.8 \text{m/s}^2$. Therefore, in case of emergency braking, the touring car bears the same basic load as the bending condition, and also bears the equivalent calculated ground braking force. The stress calculation results of the frame under this working condition are obtained, as shown in Figure 5.
It can be seen from the analysis results in Figure 5 that under the braking condition, the stress of the touring car frame is also mainly concentrated in the support pipe of the centralized prevention system and the left and right pipes connected between the boiler and the equipment warehouse. The maximum stress of the support pipe of the centralized prevention system is about 800MPa. The maximum stress on the left and right sides of the connection between the boiler and the equipment warehouse is between 230 and 250mpa. The maximum stress in other areas is below 100MPa.

4.4 Turning condition
When touring car turns during driving, it will produce centrifugal inertia force, which will have a certain impact on the body. The influence of inertia force on the frame when the vehicle turns under the limit turning condition can be simulated through the turning condition. If the road adhesion coefficient is set to 0.4, the centrifugal force is about $0.4 \times 9.8 \text{m/s}^2$. The stress calculation results of the frame under this working condition are obtained, as shown in Figure 6.

5. Strength judgment
According to the above analysis, the following conclusions can be drawn [6].

- There is a large stress area in the support pipe of the centralized prevention system of this vehicle, which is a low cycle fatigue area. It is difficult to solve the problem only by changing the size of the pipe section and the strength of the support structure.
- The local area of boiler and equipment warehouse is a relatively weak area, and early fatigue fracture will occur. In this area, the strength can be improved by appropriately increasing the section size of the longitudinal beam, increasing the connecting plate, locally selecting high-grade materials and improving the welding quality.
- The area with residual strength can further optimize the structural design and realize lightweight.

6. Conclusion
In this paper, the frame of touring car is taken as the research object, the static finite element analysis is carried out, and the four commonly used working conditions of bending, torsion, braking and turning are simulated. According to the static analysis results of the frame under the limit working conditions, the stress generated by the frame under the four typical working conditions is concentrated in the local areas of the support pipe of the centralized prevention system, the boiler and the equipment warehouse. The maximum stress of the support pipe of the centralized defense system exceeds the tensile strength of the material, and its structure needs to be redesigned. The maximum stress in local areas of boiler and equipment warehouse is close to the yield strength and needs to be strengthened locally. The analysis results provide theoretical support and guidance suggestions for the global optimization of the structure.

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