Analysis of Stiffness Performance of one Insulated Carriage

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Abstract. Based on the finite element theory, the stiffness of an insulated carriage is analysed in this paper. Different from the traditional car, the thermal insulation car puts forward higher requirements for the bending stiffness and torsional stiffness under static and full load conditions. Through the finite element stiffness analysis, the stiffness of the whole frame can be preliminarily determined. The results show that under the bending condition, the tail deformation of the carriage is large and the tail stiffness is insufficient. In the follow-up, it is necessary to improve the tail bending stiffness of the carriage through structural optimization.

1. Introduction
As the most basic and important performance index of automobile, body stiffness is not only the performance that needs to be considered in the process of body design, but also the core of evaluating the advantages and disadvantages of body structure design. Body stiffness directly affects the fatigue strength performance, passive safety performance, NVH performance and so on. Therefore, in the process of body design, we must ensure that the stiffness performance of the body structure meets the requirements in order to design a safe and reliable car body. This paper uses the digital design and development means of CAD / CAE / CAM based on CAE technology to verify the design scheme of the design engineer in the product design stage and improve the design efficiency, so as to provide theoretical support for the subsequent body structure optimization [1].

In this paper, a thermal insulation car is taken as the research object, and the finite element model of the car structure is established by using the finite element analysis technology to analyze its torsion and bending deformation. On this basis, through the relationship between force and load, the anti-bending and anti-torsion performance of BIW is qualitatively evaluated, so as to provide theoretical guidance for structural optimization and the establishment of corresponding test bench.

2. Establishment of finite element model of carriage
The accurate establishment of finite element model is the guarantee to improve the calculation accuracy. Therefore, the principle of geometric approximation must be strictly followed in the modeling process. Due to the particularity of the structure, the body in white has hundreds of structural parts and covering parts of different sizes. The structure of some parts is quite complex. In order to improve the quality of the grid, we have to simplify the modeling process.

2.1 Simplification of carriage structure
The thermal insulation carriage consists of bearing parts, auxiliary bearing parts and process decorative parts. The non-bearing parts and process decorative parts are omitted in the analysis, and only the bearing parts that have a great impact on the rigidity of the carriage are retained. Bearing parts usually have complex structures, including holes, shoulders, recesses and small geometric transition features on
the component surface. In order to improve the modeling efficiency and grid quality, they need to be rounded and smoothed.

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

![Figure 1. three-dimensional geometric analysis model of insulated carriage](image)

### 2.2 Finite element mesh generation of carriage structure

The insulation compartment is welded by rectangular pipes with various sections and steel plates. Its thickness is generally between 2mm and 5mm, and the size in other directions is much larger than the thickness. Therefore, the plate and shell element are used to discretize in the modeling process. And the shell element is used to simulate the welding between components. Because the quadrilateral element has one more node than the triangular element, and the calculation accuracy and efficiency are higher than the triangular element, the quadrilateral element is mainly selected in the modeling process. However, due to the complexity of the actual structure, in order to better simulate the geometry of the actual structure, the modeling method dominated by the quadrilateral element and assisted by the triangular element is adopted. The triangular element of the overall model is controlled within a certain range to improve the modeling accuracy and calculation efficiency. The average grid size of the structure is determined as 10mm according to the structural size of the carriage. The load of the power system, the middle partition and sliding door, the refrigeration and heating system and support at the front and upper part of the carriage, the refrigerating chamber and the refrigerating chamber are expressed by evenly distributed mass points. The model consists of 615981 elements, including 600134 quadrilateral shell elements and 15826 triangular elements. Figure 2 shows the established finite element model.

![Figure 2. element model of insulated carriage](image)

### 2.3 Material properties

The material properties involved in stiffness analysis include elastic modulus, shear modulus, density and so on. The insulation carriage studied in this paper mainly uses 06Cr19Ni10 and Q235 materials. Its material properties are follows. (1) 06Cr19Ni10 is stainless steel plate. Its elastic modulus E is $1.94 \times 10^5 MPa$. Poisson's ratio $\mu$ is 0.3. Density $\rho$ is $7.75 \times 10^{-9} t/mm^3$. Yield strength is from 205MPa to 210MPa. Tensile strength is 520MPa. (2) Q235 is rectangular tube. Its elastic modulus E is $2.1 \times 10^5 MPa$. Poisson's ratio $\mu$ is 0.3. Density $\rho$ is $7.85 \times 10^{-9} t/mm^3$. Yield strength is 235MPa. Tensile strength is from 370MPa to 500MPa.

### 3. Stiffness analysis

In the process of driving, the vehicle must bear the effects of torsion, bending and other loads. Body
stiffness is one of the most important mechanical properties of the vehicle. If the body stiffness is insufficient, the sealing strip may be lax during driving, resulting in the falling off of the sealing strip, air leakage, water inflow and other phenomena. Under severe working conditions, it may cause large deformation of door frame, window frame and other large section frames of the vehicle body, and affect the normal use and passive safety performance of the vehicle. If the stiffness design is unreasonable, it will directly or indirectly affect the dynamic response and NVH performance of the vehicle, and affect the comfort of the vehicle. Insufficient stiffness will also lead to the unstable installation of power devices and transmission devices such as engine and affect the handling and stability of the vehicle. Therefore, in the process of body design, its stiffness performance must not be too low.

During driving, the carriage is mainly subject to bending and torsion conditions. Bending stiffness refers to the ability of the carriage structure to resist bending deformation, and torsional stiffness refers to the ability of the carriage structure to resist torsional deformation. Therefore, the study of the static stiffness of the carriage is mainly to study and analyze its bending stiffness and torsional stiffness according to the structural characteristics of the carriage. The front stiffness and rear stiffness of the carriage are analyzed respectively below.

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 [4-6].

3.1 Stiffness analysis of the front of the carriage

3.1.1 Front bending stiffness analysis. The bending stiffness of the front part mainly assesses the bending stiffness of the corresponding part of the compartment refrigeration room. In the analysis, a pair of upward concentrated forces are applied at the second axle, and 1500N is applied on the left and right sides respectively to restrict the translational degrees of freedom in the X, y and Z directions at the first axle and the third axle of the carriage, and the displacement of the corresponding point of the vehicle body in the Z direction under the action of this force is calculated, as shown in Figure 3.

![Figure 3. Z-direction displacement under bending condition at the front](image1)

![Figure 4. Z-direction displacement under torsional condition at the front](image2)

Under this working condition, the z-direction displacement of car body parts at the corresponding carriage point at the second axle is 0.058103mm and 0.05821mm respectively, and the average displacement is 0.0581565mm.

3.1.2 Front torsional stiffness analysis. The torsional stiffness of the front part is the torsional stiffness of the compartment refrigerating chamber. In the analysis, a pair of upward concentrated force couples are applied at the second axle, and 1500N is applied on the left and right sides respectively to restrict the translational degrees of freedom in X, y and Z directions at the first axle and the third axle of the compartment, and the displacement of the corresponding point of the vehicle body in Z direction under the action of this force is calculated, as shown in Figure 4.

Under this working condition, the z-direction displacement of car body parts at the corresponding carriage point at the second axle is negative 0.29379mm and 0.29432mm respectively.
3.2 Stiffness analysis of the tail of the carriage

3.2.1 tail bending stiffness analysis. The bending stiffness of the tail mainly assesses the bending stiffness at the position of the freezing chamber of the insulated carriage. In the analysis, a pair of upward concentrated forces are applied at the third axle, and 1500N is applied on the left and right sides respectively to restrict the translational freedom in the X, y and Z directions at the first axle and the second axle of the carriage, and the displacement of the corresponding point of the vehicle body in the Z direction under the action of this force is calculated, as shown in Figure 5.

4. Stiffness calculation

4.1 Bending stiffness calculation

4.1.1 When the second axle bears bending load, the bending stiffness is shown in equation (1).

\[ EI = \frac{F \times L_1^3}{48 \times Z} \]  

(1)

In which, \( L_1 \) is the distance between the first axle and the third axle, and \( F \) is the applied load, and \( I \) is the Section moment of inertia, and \( E \) is the Elastic modulus of material.

4.1.2 When the third axle bears bending load, the bending stiffness is shown in equation (2).

\[ EI = \frac{F \times L_2^3}{3 \times Z} \]  

(2)

In which, \( L_2 \) is the distance between the second axle and the third axle. Other parameters are the same as above.

According to the displacement analysis results of the above bending conditions, the bending stiffness of the front and rear of the insulation compartment are calculated as 71344.655 KN·M² and 5150.41 KN·M².
4.2 Torsional stiffness calculation

When it bears torsional load, the torsional stiffness of the carriage is shown in equation (3).

\[ C_T = \frac{F \times D^2}{(\Delta Z_2 - \Delta Z_1)} \]  

(3)

In which, \( F \) indicates the applied load, \( D \) represents the distance between the left and right of the carriage, and \( \Delta Z \) represents the z-direction displacement of the corresponding carriage point at the axle.

According to the displacement analysis results of the above torsional working conditions, it is calculated that the torsional stiffness of the front and rear of the insulation compartment are 278452.3 \( N \cdot M/° \) and 188484.8 \( N \cdot M/° \).

From the above analysis results, it can be seen that the z-direction displacement of the carriage under bending condition is excessive and there is no sudden change. Under torsional condition, the torsional angle of each area changes continuously and there is no sudden change, indicating that the structural design of the insulation carriage is reasonable. The bending stiffness of the front under bending condition and the torsional stiffness of the front and tail under torsion condition are higher than those of the same type of vehicle, which can meet the use requirements. The bending stiffness of the tail under bending condition is low, so it needs to be optimized to improve the bending stiffness of the tail [7].

5. Conclusion

Based on the finite element model of an insulated car, this paper simulates the two working conditions of bending and torsion. Through the analysis, the deformation distribution nephogram and stiffness of the car structure under the two working conditions are obtained, so as to have a preliminary understanding of the stiffness performance of the car body. It is found that the bending stiffness of the rear of the car does not meet the design requirements, Structural optimization is needed to improve the stiffness performance and meet the design requirements.

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