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Stiffness Analysis of Miniature Electric Commercial Vehicle Frame Based on Lightweight Aluminum Alloy 7475 Material

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Abstract: As the performance of aluminum alloy material is close to that of steel and the density is much smaller than that of steel, it is widely used in vehicle lightweight construction. In this paper, aluminum alloy 7475 material is applied to the frame of micro-electric commercial vehicle, and the frame model is adopted by Ansys Workbench software to perform finite element analysis of mode analysis, topology optimization, bending stiffness and torsional stiffness. The results show that compared with the steel frame, the mode frequency slightly increases, and the change rate does not exceed 0.5%, and the weight decreases by 64.6%. After topology optimization, the beam reduces the excess material and optimizes the layout, and the frame weight is further reduced by 13%. The bending stiffness and torsional stiffness have reached the pre-design goals, which exceed the target value by 0.9% and 4.72% respectively. A basis is provided for structural optimization and vehicle lightweight.

1. Introduction

The car is subject to various loads such as torsion, bending and collision during use. The stiffness of the car body is one of the important mechanical properties of the car [1]. If the design of the car body is unreasonable, in the process of use, the car can be sealed unsteadily to bring air and rain leakage, which will directly or indirectly affect the phenomenon [2][3]. The vehicle's dynamic response, NVH performance, etc., adversely may affect the ride comfort and steering stability of the car, thus affecting the active safety. In addition, due to the fuel economy and other performance requirements, the car quality is as light as possible [4][5]. Therefore, the light weight and high rigidity of the car body are important goals pursued in the development and design process of the car. It is very important to study the rigidity of the car body structure [6][7]. At present pure electric mini-trucks are not restricted by the license plate, and are favoured by the majority of logistics transporters. However, the current life of pure electric vehicle battery is limited, and it is more and more important to reduce the weight of the structure [8][9]. However, the optimization space of steel has been small, and the aluminium alloy has about one-third of the steel density. Thus of the frame weight can be significantly reduced, which can greatly improve the cruising range of new energy vehicles [10][11].

7475 aluminum alloy belongs to Al-Zn-Mg-Cu alloy, mainly used for aluminum and uncoated aluminum plates for fuselage, wing frame, purlin and so on and other high strength and high fracture toughness parts. In this paper, the modal of the 7475 aluminum alloy frame of the miniature electric commercial vehicle is calculated by the finite element method, and compared with the modal of the steel frame. Based on this model, the topology of the 7475 aluminum alloy frame is optimized. Then calculate the bending stiffness and torsional stiffness of the vehicle and compare it with the benchmark value.

2. Theoretical basis

2.1 Bending stiffness

In the calculation of bending stiffness, the frame can be simulated as a simply supported beam mechanism, and the stiffness is calculated as shown in equation (1) [12].

$$C_B = \frac{a^3}{48} \times \frac{F}{h} \tag{1}$$

Where, C_B is the bending stiffness (N·m^2), F is the applied load (N), a is the wheelbase (m) when the frame stiffness is calculated, and h is the deflection (m) at the point of load application. Bending stiffness is calculated by constraining the three degrees of freedom of UX, UY and UZ at the support of the left and right coil springs before installation, and then constraining the UY and UZ of the front and rear lifting ears of the leaf spring and the bearings between the two. The displacement degree in the Z direction is constrained at the joint between the leaf spring and the wheel, and the vertical downward load force is applied 1000 N, so that the frame is only bent and deformed, and the boundary conditions and load conditions are arranged.

2.2 Torsional stiffness

When calculating the torsional rigidity of the frame, the frame is only subject to torsional deformation, and the formula for calculating the torsional stiffness is Equation (2)[2].

$$c = \frac{\pi l^2}{180} \cdot \frac{F}{2\Delta u} \tag{2}$$

Where, l is the distance between the left and right constraints, F is the applied force, and Δu is the displacement value in the center z direction of the left and right sides of the middle support of the two lifting ears. The calculation method of torsional stiffness is to constrain the degrees of freedom of the four directions of UX, UY, UZ, and ROTY at the support of the left and right coil springs before installation, which only retains the degrees of freedom in both directions of ROTX and ROTZ, and then constrain the leaf springs after installation. Two equal and opposite forces are applied to the left and right sides of the front and rear lug support and the support between them, that is, a torque is applied to the whole vehicle.

3. Model building and modal analysis

3.1 building model

The quality of the meshing tends to have a large impact on the finite element analysis structure. Since the frame model is too complicated after the structure is lightweight, the hexahedral mesh cannot be used, so the tetrahedral mesh is used when meshing. The average mesh quality classification is 0.6~0.8 for general quality, and 0.8~1 is high quality mesh. If the mesh is the finer, the quality is the higher, and if the calculation time is the longer, the computer requirements are the greater. Under the premise of performance satisfaction, the mesh quality is increased to 0.68 to ensure the reliability of the calculation results.

3.2 Mode analysis

Table 1. Natural frequency of the frame under different materials

No	Aluminum Alloy /Hz	Steel/Hz	difference/Hz	rate of change
1	12.602	12.586	0.016	0.13
2	19.315	19.261	0.054	0.28
3	34.581	34.437	0.144	0.42
4	35.658	35.507	0.151	0.43
5	46.543	46.408	0.135	0.29
6	48.137	47.969	0.168	0.35
7	57.522	57.349	0.173	0.3

The Block Lanczos method was used to analyze the aluminum alloy material and the steel frame modal. The first seven-order pairs of the mode frequency before and after the aluminum alloy replaced the steel are shown in Table 1. As can be seen from the table, the modal of the aluminum alloy 7475 The frequency is slightly higher than that of steel at all stages, the rate of change does not exceed 0.5%, while the weight of steel frame is 249.29, and the frame of aluminum alloy is only 175.93 kg, which is 87.965 kg less, a decrease of 64.7%. The first-order torsional mode matrix is shown in Figure 1. The first-order torsional frequency of the whole vehicle is 19.315 Hz. As can be seen from the figure, the section line of the vibrating type is located at the lower part of the front end of the vehicle body, and the rear end of the two longitudinal beams is a vibrating abdomen. This mode can be aroused when the vehicle body is subject to excitation from the road left and right sides.

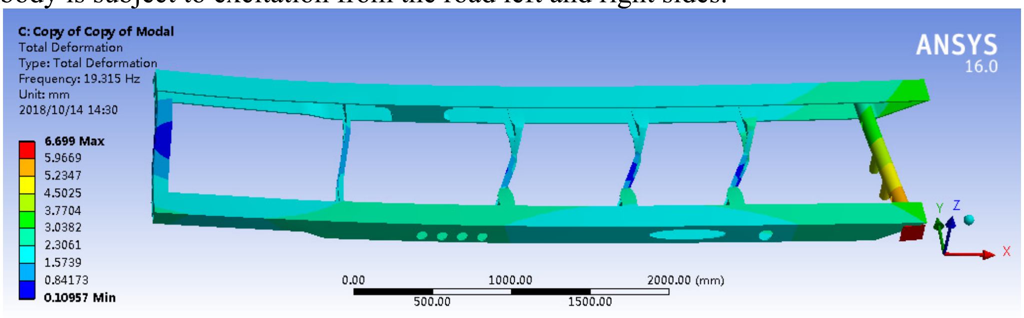

Figure 1. First order torsional mode

4. Topology optimization and stiffness calculation

4.1 Topology Optimization

The ansys workbench topology optimization design will be used to calculate the irremovable area of the frame under various working conditions, and the beam will be assembled in the non-removable area. At this time, the beam is the best position of the frame. The selection of the optimal position of the beam is beneficial to the weight reduction of the frame, which not only reduces the burden on the stringer, but also reduces the quality of the beam and reduces the weight of the beam. Through the initial establishment of the frame model, the number of beams and the optimal arrangement position of the beam are determined by Ansys workbench topology optimization. The boundary conditions of the position are derived from the four working conditions often encountered by the frame, and the four working conditions are full load static. The bending condition during horizontal driving and the torsion condition of each wheel may be falling into the pit. The position of the beam arrangement optimized by Ansys workbench topology can effectively support the force of the frame longitudinal beam under four working conditions, and can also effectively reduce the arrangement of redundant beams under the premise of meeting the frame force, reducing unnecessary Waste of materials. Figure 2 is the topology optimization result of one of the working conditions. The Ansys workbench topology is used to optimize the design of the frame beam position. It can be adjusted within a reasonable range.

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In actual production, it can also be based on motor size, drive shaft size, clutch. The size of the battery, the size of the battery box, and the size of the special equipment are used to fine-tune the beam position. After optimization, the weight of several beams of the aluminum alloy 7475 frame is reduced by 22.8 kg, which is reduced by about 13%.

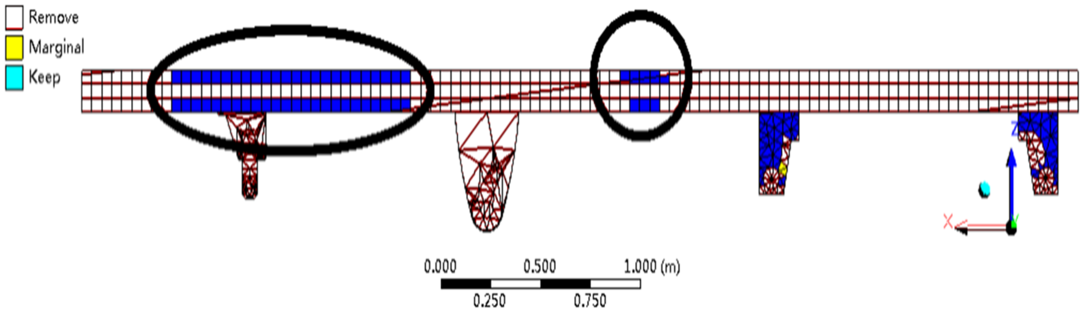

Figure 2. Topology optimization under the condition of a working condition

4.2 Bending stiffness

In the analysis, the sketch of the leaf spring of the frame is modeled, the displacement degree of displacement in the Z direction is constrained at the joint between the leaf spring and the wheel, and the vertical 1000N force is applied at the midpoint of the two longitudinal beams to make the car The frame only undergoes bending deformation.

The defined boundary conditions and load conditions are submitted to Ansys workbench for analysis, and the Total Deformation cloud image is output. The Total Deformation result cloud diagram is shown in Figure 3. It can be seen from the result cloud diagram that the maximum displacement of the frame occurs between the beam 2 and the beam 3, which conforms to the basic law of theoretical mechanics. The maximum deflection of 0.373 mm is brought into the formula (1) to obtain CB=1.226×10^6 N·m^2. It is higher than the reference target value of 1.215×10^6 N·m^2, which is 1.1×10^4 N·m^2 more than the target value of the target vehicle, exceeding 0.9%, meeting the design requirements.

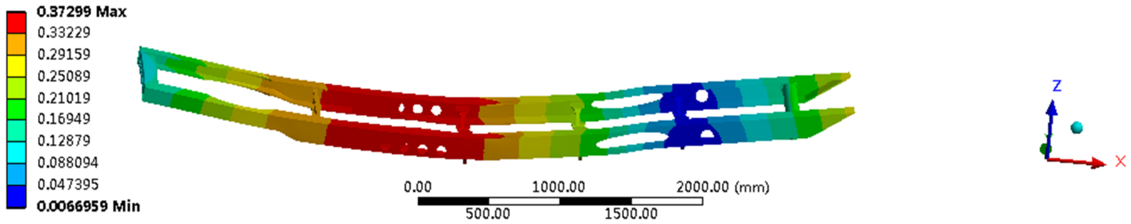

Figure 3. Frame bending displacement deformation cloud map

4.3 Torsional stiffness calculation

When the freedom of movement in the X, Y, and Z directions of the left and right front leaf spring joints of the frame is constrained, the degrees of freedom in the X, Y, and Z directions are restricted at the right rear leaf spring link, and apply the Z axis to the left rear leaf spring link. The force with the same positive direction is 1000N. The displacement result cloud image calculated by Ansys workbench is shown in Figure 4. From the result, the maximum displacement of the frame under the action of F=1000N is 5.63mm, and the deflection h=5.63mm is brought into the formula (2) to obtain the torsional stiffness CT=2618 N•m/°, which is 2500 N•m/°compared with the enterprise target reference frame torsional stiffness. It is much higher than the benchmark target value of 118 N•m/°, exceeding 4.72%, in line with design requirements.

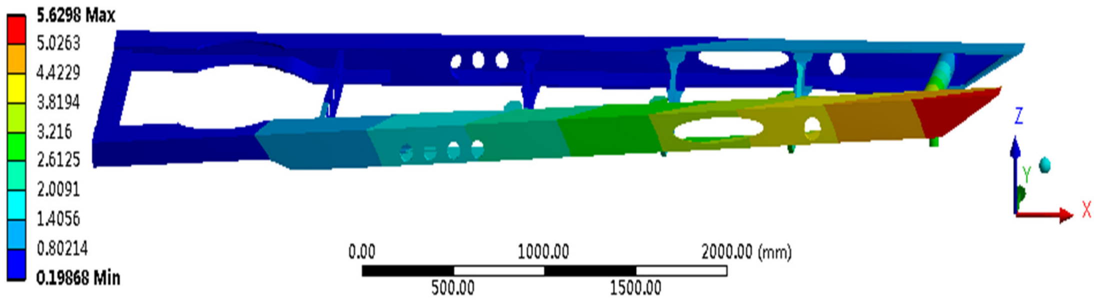

Figure 4. Frame torsional displacement deformation cloud map

5.Conclusions

(1) The aluminum alloy 7475 is used to replace the micro electric vehicle steel frame. The mode frequency does not change much, slightly increases, the change rate does not exceed 0.5%, and the steel frame weight is 249.29 kg, and the aluminium alloy frame can be less 87.965 kg, which is a decrease of 64.7%.

(2) After optimizing the topology of the aluminum alloy 7475 frame, the arrangement of the excess beam is effectively reduced, and the waste of excess materials is reduced, and the weight of the aluminum alloy 7475 electric commercial vehicle frame is reduced by 13%.

(3) The bending stiffness and torsional stiffness of the aluminum alloy 7475 frame after topology optimization have reached the pre-designed target, which exceeds the target value by 0.9% and 4.72%, respectively.

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