Determination and Performance Analysis on Miniature and Electric Commercial Vehicle Frames of Carbon Fiber Materials in the Laying Mode

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Abstract: The concept three-dimensional model of the mini commercial vehicle was established, and the vehicle parameters and calculation conditions were defined. The stress direction and value of the beam were calculated by Ansys workbench, and the laying method of the carbon fiber material of the beam was determined to be \([0^\circ, 90^\circ, 45^\circ, 90^\circ, 0^\circ]\) of the five-layer layup sequence, using the Abaqus software analyzes the frame made of carbon fiber composite material. It is found that the degree of Hill failure is 23.88\% on the beam 3 under the working condition 1, and the damage of the beam 4 is 33.92\% under the working condition 4, and the damage degree is less than 100\%. The modal analysis results of the whole frame show that torsional mode and bending mode frequency of the first-order are 51.741 Hz and 62.286 Hz, exceeding 48\% and 58\% of the target value, respectively, which meet the target requirements. Carbon fiber materials provide an important basis for the application of miniature commercial vehicle frames.

1. Introduction
The emission regulations of countries all over the world are becoming more and more strict, and the energy crisis is becoming more and more serious. How to reduce fuel consumption and reduce emissions under the premise of ensuring safety and power is an urgent problem that the automobile industry needs to solve[1]. Replacing traditional materials such as metals with various lightweight materials, making cars lightweight is an important way to achieve energy saving and emission reduction[2][3]. According to research data, the traditional energy vehicle body consumes about 70\% of its own fuel weight. If the weight of the whole vehicle is reduced by 10\%, the fuel consumption can be reduced by 6\%-8\%[4]. At present, carbon fiber composite materials are used in mass production cases of body and parts. These vehicles are basically high-end cars such as BMW i3, i8 and 7 series.
and Mercedes-Benz SLR sports car[5][6]. The application of carbon fiber in new energy trucks has not been reported yet.

This paper firstly establishes the frame model of the miniature electric truck, analyzes the working conditions, the finite element calculation is to analyze and determine the laying mode of the carbon fiber frame, and failure criterion determination of the carbon fiber frame model is to carry out.

2. Frame model establishment and application of boundary conditions

2.1 Model establishment

According to the similar models, the frame structure is selected as the side beam structure, and the side beam structure is mainly composed of two longitudinal beams and a plurality of beams, wherein the frame longitudinal beam is mainly for carrying. The Catia software is used to build a simple model. The longitudinal beam of the frame is built according to the size. The longitudinal beam adopts a trough structure. The distance between the longitudinal beams according to the wheelbase is 1300mm. The length of the longitudinal beam is 5000mm according to the length of the front and the cargo box. The wall thickness is 6mm, and the front suspension and rear suspension are built according to similar models.

The modification of the truck is mainly carried out from the frame. The installation of various special functions requires the support of the frame. Therefore, the frame needs to be modified when designing the frame. In particular, the beam needs to be changed according to other link components. Location, to facilitate the installation of a variety of special equipment on the future frame. The position of the beam is not unique. Using Ansys workbench to optimize the design of the frame beam position is a design that can be adjusted within a reasonable range. In actual production, it can also be based on motor size, drive shaft size, clutch size, and battery box size. And the size of the beam is adjusted by special equipment.

2.2 Determination of working conditions

The quality parameters of the miniature electric commercial vehicle include the whole vehicle preparation mass m0, passenger capacity, loading quality, total vehicle mass ma, and axle load. Loading quality refers to the quality of the vehicle with all the equipment on the vehicle, full of fuel, water, and full and manned. Set the number of passengers in the car to be 2, the per capita quality is 75KG, set the car loadable me to 1500KG, the car's curb weight is 1400KG, and the loading mass is 3050KG. The other quality parameters in the curb weight are set as shown in Table 1. Through the shape optimization design of Ansys workbench to calculate the optimal position of the beam [6], there are four kinds of severe working conditions in the frame during the driving process, which are static or curved when driving on a straight road[6].

| Part name        | M(kg) | Part name        | M(kg) |
|------------------|-------|------------------|-------|
| frame            | 180   | steering system  | 40    | Motor | 90   |
| Front axle       | 110   | Braking System   | 15    | Electrical System | 30   |
| Rear axle        | 150   | Front suspension | 35    | Container | 160  |

![Frame assembly drawing](image)
3. Determination of the laying method of carbon fiber materials

3.1 Analysis of laying methods

In carbon fiber composites, the main role of the fiber is to carry the load, and the load direction is consistent with the fiber direction to maximize the high performance of the carbon fiber composite. The layup methods are usually 0°, 90° and ±45°. It is experimentally demonstrated that the 0° layup is used to resist axial loads, the 90° layup is used to resist lateral loads, and the ±45° is used to withstand shear loads. Therefore, for the choice of the lamination method, it is necessary to clarify the force characteristics of the three beams of the frame to select whether the ply layer intersecting 0° and 90° is a multi-directional ply of 0°, 90° and ±45°.

In the Ansys workbench, the frame beam 2, the beam 3 and the beam 4 are subjected to force reaction under various working conditions to output the force of each group. The interaction force between the beam wing and the longitudinal beam is as shown in Table 2. It is not difficult to find that the maximum interaction force of the beam 3 appears in the working condition 1, the size is 5420.2N, and the maximum component force in the X direction is 5057.8N. The maximum combined force of the beam 4 appears in the working condition 4, the maximum combined force is 9081.5, and the maximum component force appears in the X direction, and the size is 9081.5N. The maximum combined force of the beam 5 also appears in the working condition 4, the maximum combined force is 7291.5N, the maximum component force appears in the Y direction, and the size is 6533N. From the above calculation data, it is concluded that the frame beam of the frame receives a larger component force in both the X and Y directions, and the component force in the Z direction is relatively smaller.

Table 2. The magnitude and direction of interaction between each beam and longitudinal beam

| DWC  | DIFBW | Beam wing plate interaction force (N) | Left longitudinal beam | Right longitudinal beam |
|------|-------|-------------------------------------|------------------------|-------------------------|
|      |       | Beam 3     | Beam 4     | Beam 5     | Beam 3     | Beam 4     | Beam 5     |
| WC1  |       |            |            |            |            |            |            |
| X    |       | -5057.8    | -3511.7    | -1286     | -5057.8    | -3511.7    | -1286     |
| Y    |       | 1877.1     | 462.4      | 2175.2    | -1877.1    | -462.4     | -2175.2   |
| Z    |       | -522.73    | -1009.2    | -2157.4   | -522.73    | -1009.2    | -2157.4   |
| Total|       | 5420.2     | 3683       | 3322.6    | 5420.2     | 3683       | 3322.6    |
| X    |       | 1651       | -1973.3    | 698.64    | 800.57     | -1597.2    | 860.2     |
| WC2  |       |            |            |            |            |            |            |
| X    |       | -670.33    | -716.99    | 522.38    | 683.1      | -545.57    | 86.467    |
| Y    |       | -1103.1    | -1496.4    | -1965.5   | -1143.4    | -1622.7    | -2003.3   |
| Z    |       | -474.66    | -1973.3    | -622.4    | -772.39    | -1342.9    | 2350.3    |
| Total|       | 2095.7     | 2578       | 2150.3    | 1554       | 2341.3     | 2181.9    |
| X    |       | 747.8      | -6445.2    | -2214.9   | -772.39    | 1342.9     | 2350.3    |
| WC3  |       |            |            |            |            |            |            |
| X    |       | -2360.9    | -5132.2    | -5640.6   | -2833.2    | -3370.5    | -4652.3   |
| Y    |       | -326.26    | -169.99    | -2132.9   | -551.9     | -2077.4    | -2045.4   |
| Z    |       | 2497.9     | 8240.7     | 6424.2    | 2988       | 4180.8     | 5599.3    |
| Total|       | -327.37    | 1802.8     | 2583.6    | 184.23     | -6882.2    | -2375.2   |
| X    |       | 3312.9     | 3664.4     | 4814.8    | 3869.8     | 5925.3     | 6533      |
| Y    |       | -534.09    | -2105.7    | -2032.4   | -274.66    | -2874.6    | -2201.2   |
| Z    |       | 3371.6     | 4594.7     | 5829.9    | 3883.9     | 9081.5     | 7291.6    |

DWC--Driving Working condition; WC1- Working condition 1; WC2- Working condition 2;
WC3- Working condition 3; WC4- Working condition 4; DIFBW-- Direction of the interaction force of the beam wing

3.2 Selection of beam web paving method

Table 3. Normal and shear stress of webs of beams

| DWC  | Beam 3 | Beam 4 | Beam 5 | Beam 3 | Beam 4 | Beam 5 |
|------|--------|--------|--------|--------|--------|--------|
| WC1  | 38.560 | 17.440 | 34.218 | 5.740  | 4.914  | 10.483 |
| WC2  | 5.116  | 11.556 | 16.923 | 1.206  | 3.440  | 5.546  |
| WC3  | 23.321 | 20.530 | 30.169 | 6.460  | 11.545 | 10.566 |
| WC4  | 25.638 | 18.59  | 34.45  | 8.166  | 13.997 | 10.816 |

Only the strong direction is not enough to verify that the tangential direction is not affected or the force is small. The Ansys workbench is needed to calculate the normal and shear stress between the frame beam and the longitudinal beam contact surface and compare and analyze them. The frame beam web is linked with the wing plate, and the force is proportional to the wing plate, so no further measurement is needed. The positive stress and shear stress are analyzed by Ansys workbench as shown in Table 3. Through the above analysis, it can be clearly seen that the normal stress of the frame web is greater than the shear stress under various working conditions, so the same layering method as the wing plate is also selected, and the layering sequence and the layering angle are [0°,90°,45°,90°,0°].

4. Performance analysis

4.1 Mode analysis

In order to verify whether the upper body design meets the requirements of the whole vehicle, the upper body digital model is mounted in the original body digital model for modal analysis. The analysis results are shown in Table 4, first-order torsion mode frequency, first-order bending mode. The frequencies are 51.741 Hz and 62.286 Hz, respectively, which meet the target requirements, respectively exceeding 48% and 58% of the target value. The first-order torsion mode shape is shown in Figure 2.

Table 4. Comparison of frame modal frequency and target value

| Modal mode       | Analysis result(Hz) | goal(Hz) |
|------------------|---------------------|----------|
| First order twist| 51.741              | 35       |
| First-order bending| 62.286              | 40       |

Figure 2. First-order bending mode shape cloud image

4.2 Performance analysis

Compared with Ansys workbench, the advantage of Abaqus software lies in the analysis of materials. It can simulate many physical properties such as metal, composite, concrete and polymer materials. This
is what Ansys workbench can’t do. The feasibility of carbon fiber composite material is discussed by the Tsai-Hill failure criterion[7]. The defined composite material is layered in the order of five layers of [0°, 90°, 45°, 90°, 0°], and finally the geometric model of the frame beam is introduced into Abaqus to give the model composite properties. The load is applied to the surface in accordance with the force conditions in the above table. Finally, the defined work was submitted to Abaqus for stress analysis.

Through the Abaqus calculation, the beam 3 made of carbon fiber composite material has a failure rate of 23.88% under the working condition 1, and the degree of damage of the beam 4 is 33.92% under the working condition 4. Both are less than 100%, so it is considered that the carbon fiber composite material is safely used in the beam 3, the beam 4 and the beam 5 by Abaqus finite element analysis, and does not satisfy the Tsai-Hill failure condition. The beam 3 under the working condition 1 is shown in Figure 3.

![Figure 3 Tsai-hill failure analysis result cloud diagram of beam 3 under working condition 1](image)

5. Conclusion

From the above studies, we can draw the following conclusions:

1) The carbon brazing frame beam has the same web and wing cladding, and adopts five layers, from 0°, 90°, 45°, 90° and 0° from the inside to the outside.

2) The finite element modal analysis of the carbon brazed frame shows that the first-order torsional mode frequency and the first-order bending mode frequency are 51.741 Hz and 62.286 Hz, respectively, which meet the target requirements, respectively exceeding 48% and 58% of the target value.

3) Under the four working conditions, the Tsai-Hill damage degree of the three beams is far less than 100%.

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