Mechanical characteristic and improvement of the frame of the light electric sanitation vehicle

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Abstract

Aiming at the complex mechanical characteristic of the frame of the light electric sanitation vehicle under various working conditions, the finite element method is used. Based on the whole vehicle model established in the three-dimensional software, the statics characteristic is analyzed, and the displacement and the stress diagrams are gotten under typical working conditions. The improvement is carried out for the frame structure, and the corresponding statics characteristic is analyzed and verified. The results show that the mechanical property is significantly improved and the improved frame satisfies the design requirements. The influence on the vehicle driving characteristic is analyzed, which lays a foundation for the relative experiment, dynamics analysis and structural improvement of the frame.

Key words: Electric sanitation vehicle; frame; statics analysis; finite element analysis

1. Introduction

With the rapid development of urban construction in China, the disposal and transportation of garbage has become an important part of urban sanitation work. The sanitation vehicle that acts as a garbage transfer device plays an important role. It not only saves manpower and material resources, but also improves the efficiency of sanitation work. In recent years, the traditional vehicle has begun to transform into the new energy vehicle represented by the electric vehicle [1,2], and the electric sanitation vehicle has also become the development direction of the sanitation vehicle. The electric vehicle not only can achieve zero emissions, but also has the advantages of low noise and high energy conversion efficiency. The frame of the electric sanitation vehicle is not only the carrier of the battery and the garbage box, but also bears various shocks and vibrations during the running of the vehicle [3,4], so the performance of the frame directly affects the stability and safety of the vehicle [5]. If the design and strength check of the frame are carried out by using the classical empirical formulas of material mechanics, elastic mechanics and structural mechanics, it will inevitably lead to the unreasonable distribution of strength in each part [6], the appropriate model simplification is not easy, and the reliability of the result will be reduced [7].

In order to solve the above problems, this study is aimed at the mechanical analysis and improvement of a light electric sanitation vehicle frame. Specifically, the vehicle model is built by the three-dimensional software, and the vehicle model is simplified. The simplified vehicle model is introduced into the finite element analysis software ANSYS Workbench to establish a finite element model, and the static analysis and modal analysis of the frame are carried out. According to the results of static analysis, the frame is improved, and the improved frame is validated by static analysis. The results can lay solid foundations for the relevant experiments, dynamic analysis and calculation as well as the structure optimization design for the vehicle frame.

2. Working Condition and Boundary Condition

The force of the frame is very complicated, and the force analysis of the four most typical working conditions which are bending condition, torsion condition, braking condition and turning condition is usually carried out on the frame [8]. The bending condition is analyzed here. The boundary condition is the expression of the actual working condition in the finite element model [9]. The reference coordinate system of the model is shown in Figure 1. According to the bending condition, the constraints imposed on the model are the translation X, Y, Z of the left front wheel, the translation X, Z of the right front wheel, the translation Y, Z of the left rear wheel and the translation Z of the right rear wheel.

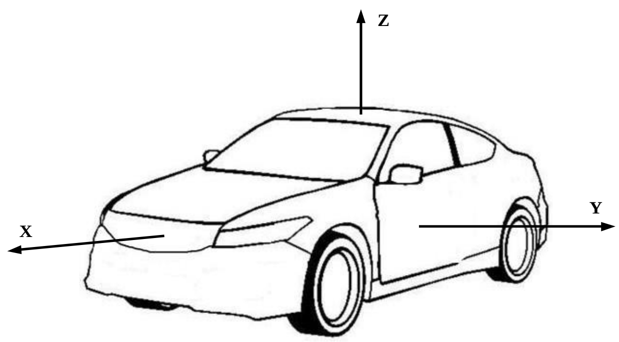


Figure 1 Vehicle coordinates system

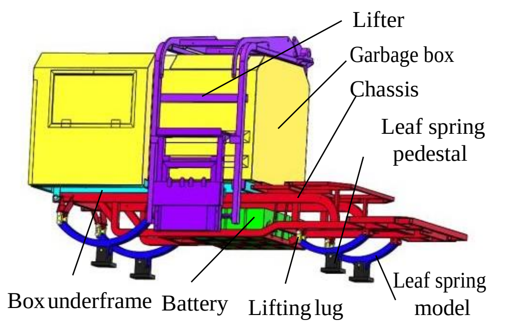
3. Establishment of Geometry Model and Finite Element Model

3.1 Determination of parameters and simplification of the model

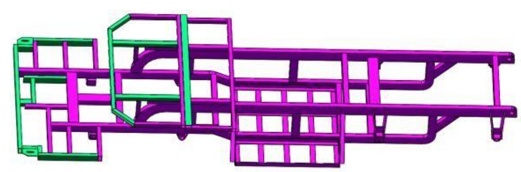
The 3D model of the vehicle is established and simplified as shown in Figure 2. As shown in Figure 2(a), the vehicle consists of a cab, a lifter, a garbage box, a frame, a chassis, a battery, a lifting lug, a leaf spring and a leaf spring base. For the smooth progress of the analysis, the vehicle model is reasonably simplified. Because the frame is welded from proximate materials and sheet materials, the frame is modeled as a whole body.

The cab, the garbage, the garbage box, the lifter, the wheels, the front axle, the rear axle, the drive motor and the battery are replaced with an equivalent model. Because the shape of the cab is complex, the cab is simplified to reduce the number of grids and shorten the calculation time. Because the garbage, the garbage box, the lifter mechanism, the wheels, the front axle, the rear axle and the drive motor are not directly in contact with the frame, the simplified processing of this part does not affect the accuracy of the frame analysis, and also greatly reduces the number of grids to shorten the calculation time. When the battery is placed on the battery holder, only the four sides of the bottom of the battery are in contact with the battery holder, and the middle portion of the bottom of the battery is not in contact with any object, so the middle of the battery can be cut off to reduce the number of grids and speed up the calculation.

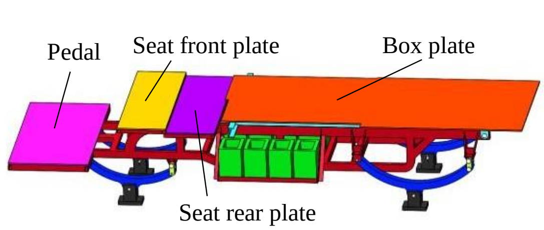
According to the relative position and interaction relationship of each part of the vehicle, the quality of each equivalent model is determined, and the mass center of the equivalent model is adjusted. The mass of the cab is allocated based on the ratio of the longitudinal length to the total longitudinal length of the pedals, the seat front plate and the seat rear plate; the mass of the primary and secondary drivers is attached to the seat front plate; the mass of the garbage, the garbage box and the lifter are equivalently replaced by a box plate; the mass of the single front leaf spring and the half front axle is equivalently replaced by a front leaf spring model; the mass of the wheel is equivalently replaced by a leaf spring pedestal; the mass of a single rear leaf spring, half rear axle and half drive motor is equivalently replaced by a single rear leaf spring model; the mass of the battery is equivalently replaced by a battery model. The box plate is composed of four equal-thickness plates according to the bottom size of the garbage box. By adjusting the length and width of the four plates, the x, y coordinates of the mass center of the box plate are coincided with the x, y coordinates of the total mass center of the garbage box, the garbage and the lifter, and finally the box plate is modeled as a whole.



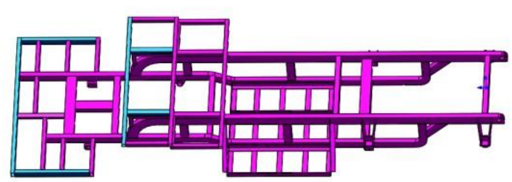
(a) Whole vehicle model without the cab



(b) Frame model



(c) Simplified whole vehicle model



(d) Simplified frame model

Figure 2 Establishment and simplification of 3D model

3.2 Establishment of the finite element model

The vehicle model material parameters need to be determined. There are two types of models in the vehicle model. One is the physical model and the other is the equivalent model. The physical model is defined according to the physical material parameter, and the density of the equivalent model is obtained according to the volume of the model and the mass of the distribution.

The corresponding contact connection needs to be defined. The pedal, the seat front plate and the seat rear pleat are defined as Bonded contacts; the box plate and the box underframe are defined as Bonded contacts; the contact between the frame and the box underframe is defined as Frictional contact; a frictional contact, a Bonded contact and a Revolute connection are added to the frame and the box underframe, the frame and the leaf spring model, the frame and the lifting lugs.

The lifting lug and the leaf spring model, the pin connection of the lifting lug and the leaf spring pedestal. The contact of the pin with one component is defined as a bonded contact, and the contact of the pin with the other component is set to a frictional contact and a rotational connection. The bottom of the battery is defined as a bonded contact with the battery holder. Since the actual elastic modulus of the leaf spring is unknown and the following part of the leaf spring model has no influence on the analysis result of the frame, the leaf spring model, the lifting lugs, the leaf spring pedestal, the pin shaft and the split pin is set as a rigid body.

Meshing is an important step in finite element analysis. The quality of the mesh directly affects the accuracy of the final result, and the number of meshes directly affects the scale of the calculation. Therefore, it is necessary to pay attention to the balance of the quality and quantity of the mesh in establishing the meshing model. In addition to the line unit and the point unit, a unit quality factor is calculated based on the ratio of the given unit volume to the side length, and a comprehensive quality metric is provided and the range is 0-1.The 1 represents a perfect cube or square, and the 0 represents a unit volume of zero or negative. The mean value of the grid quality in this study is guaranteed to be above 0.7.

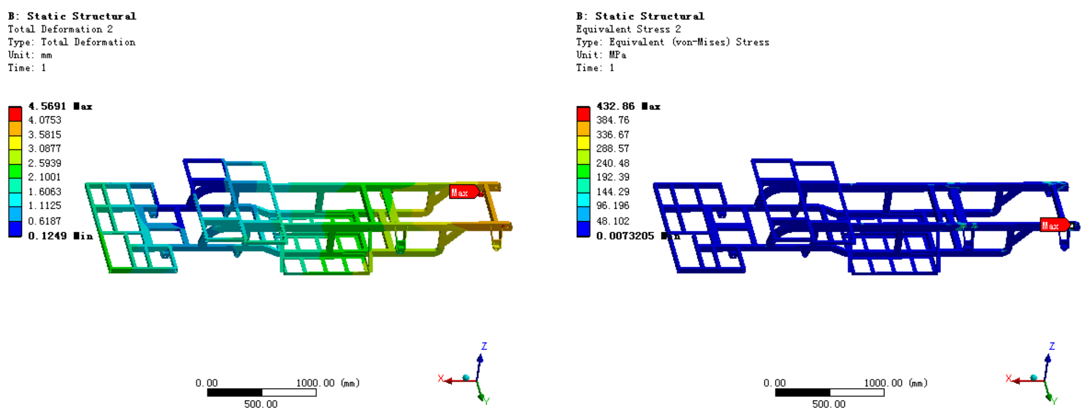
4. Static Analysis before Improvement

The material parameters are defined for each part of the model. The frame material is 20# steel, the yield limit of 20# steel is 275 MPa, Poisson's ratio is 0.3, the modulus of elasticity is 206 GPa, and the density is 7850kg/m^3. For the convenience of calculation, the elastic modulus and Poisson's ratio of the pedal, the seat front plate, the seat back plate, the box plate, the front spring model, the rear spring pedestal and the battery model are consistent with the frame material. The density of the equivalent model is obtained from the mass and volume of the equivalent model, as shown in Table 1.

Table 1 Material density of the equivalent model

Name	Foot plate	Driving seat plate	Back seat plate	Carriage plate	Front leaf spring	Front leaf spring bed	Rear leaf spring	Rear leaf spring bed	Battery pack
Density (kg/m^3)	10103	43487	10667	110434	6986	11544	9191	11248	5342

In this section, the static analysis of the frame of the electric sanitation vehicle is carried out. When the full-loaded vehicle is under the bending condition, the stress and displacement of the frame is shown in Figure 3. The maximum displacement of the frame is 4.569mm, which appears in the right rear position of the frame. It can be seen from the displacement cloud diagram that the displacement of the left side of the frame is larger than the displacement of the right side of the frame when the vehicle is full-loaded, which indicates that the mass center of the vehicle is to the left. Therefore, the force in the left-center position of the frame is more stressed than the right-center position, so that the right rear corner of the frame is tilted upwards and there is a squeeze of the garbage box underframe, which causes the maximum displacement to occur at the position. The left deviation mass center causes problems such as insufficient steering when the vehicle turns to the right, excessive steering when the vehicle turns to the left, and running deviation. Moreover, it can be seen from the displacement cloud diagram of the frame that the large displacement of the frame is at the rear end of the frame, and the displacement of the front section of the frame is generally small, so it can be inferred that the mass center of the vehicle has a rear deviation mass center. This will cause a large displacement of the rear end of the frame, which will easily lead to fatigue failure of the frame and insufficient steering of the vehicle. It can be seen from the stress cloud diagram that the connection between the rear leaf spring and the longitudinal beam of the frame needs to be subjected to a large stress, and the maximum stress reaches 432.86 MPa, which far exceeds the yield strength of 20# steel of 275 MPa. Therefore, the frame is prone to plastic displacement or fracture damage. In summary, the frame cannot meet the design requirements and needs to be improved.



(a) Displacement (b)Stress

Figure 3 Stress and displacement under the full load bending condition

5. Improvement of the Frame

For the left-center and rear-center problems of the mass center, a method of adjusting the position of some batteries is proposed. Since the right front position of the carriage is equipped with a lifter, the battery cannot be installed at the middle of the right side of the frame. To avoid a right-centered center of mass in the rear half of the vehicle, the left side of the frame should retain the battery mounting position. According to the actual situation, two of the four batteries on the left side of the frame are longitudinally mounted in the right front position of the frame, and the other two batteries are longitudinally installed in the middle of the left side of the frame. The improved frame is shown in Figure 4. The addition of the beam 3 not only increases the rigidity of the battery frame, but also solves the problem of insufficient strength of the front part of the frame obtained by modal analysis. For the problem of large stress at the joint between the rear leaf spring and the frame, an angle iron is added there to increase the strength and increase the thickness of the two vertical boards at the joint. The thickness of the added angle iron is 3 mm, and the thickness of the two vertical boards at the joint is increased from 8 mm to 10 mm.

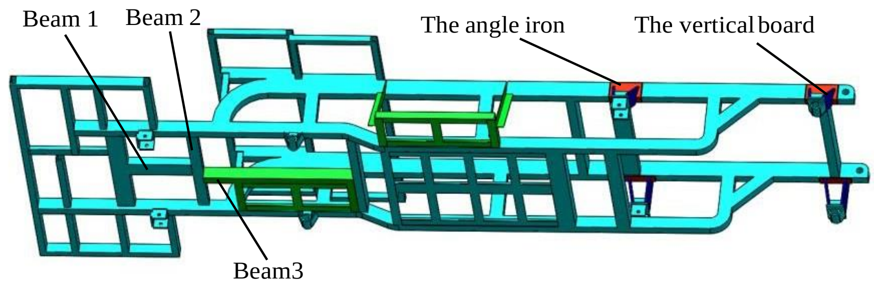
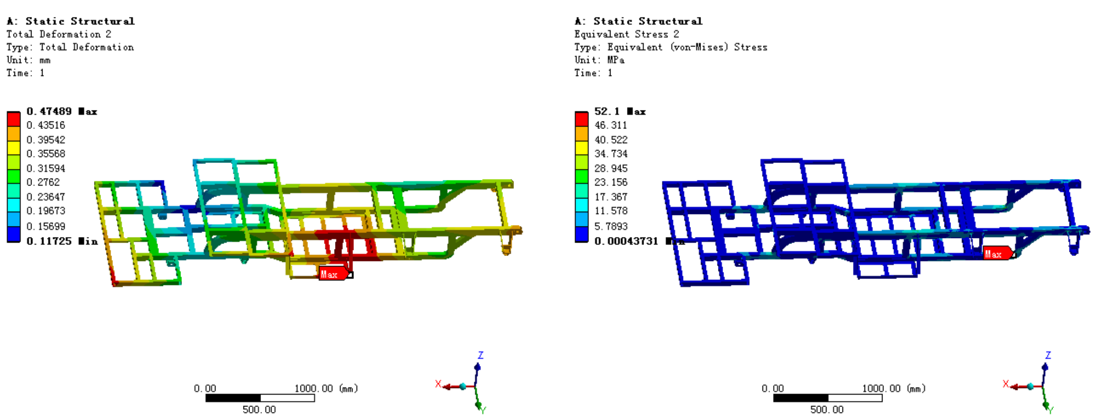


Figure 4 Improved frame

6. Improved Static Analysis

The improved frame is analyzed under the full-load bending condition. When the vehicle is under the full load bending condition, the stress cloud diagram and displacement cloud diagram of the frame are shown in Figure 5. The maximum displacement of the frame is 0.475mm, which appears in the rear part of the left battery frame of the frame. The maximum stress of the frame is 52.1 MPa, which appears in the bent position on the left side of the frame. The front leaf spring is connected to the lower longitudinal beam of the frame and the rear leaf spring is connected to the upper longitudinal beam of the frame. In addition, more batteries are installed in the middle of the frame, and the battery frame on the left side of the frame is in the form of a cantilever. Therefore, it is reasonable that the maximum displacement appears on the rear of the battery frame on the left side of the frame. It can be seen from the displacement cloud diagram that the problem of the left-center and right-center mass center of the vehicle has been greatly improved.



(a)Displacement (b)Stress

Figure 5 Improved stress-displacement under the full load bending condition

After improvement, the maximum displacement of the frame has been reduced from 4.569mm to 0.475mm, so the problem of excessive displacement of the frame has also been greatly solved. Since the vehicle still has a slight left-centered center of mass and the force on the left side of the frame is greater than the force on the right side, it is reasonable that the maximum stress appears on the left side of the frame. Because the front leaf spring of the frame is connected to the lower longitudinal beam of the frame, the rear leaf spring of the frame is connected with the upper longitudinal beam of the frame, and the battery frame is mounted on the lower longitudinal beam.

Therefore, it is reasonable that the maximum stress of the frame appears at the bend of the lower longitudinal beam, which is prone to stress concentration at a certain angle, on the left side of the frame. After improvement, the maximum stress of the frame is reduced to 52.1 MPa form 432.86 MPa, and the maximum stress safety factor is 5.3, which is greater than the safety factor of 1.5 required by the design. Therefore, the stress analysis result is reasonable. In summary, the improved frame meets the design requirements under the full-load bending condition.

7 Conclusions

The three-dimensional model of the whole vehicle is built in the three-dimensional software, and the whole vehicle is reasonably simplified. The simplified vehicle simplified model is imported into the finite element analysis software for static analysis. Through the static analysis of the frame, the original design is found to be insufficient, and the original design is improved and analyzed. Then the stress and displacement cloud diagram of the improved frame under the bending is obtained. The influence of the results on the vehicle is analyzed, which provides a foundation for the relevant experiments, dynamic analysis and structural improvement of the frame.

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