Research on Static Analysis of the Vehicle Frame based on Finite Element Analysis

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Abstract— Aiming at the problem of complex transfer relationship of force and deformation in the vehicle frame, the finite element method is used to study the displacement and stress distribution. The vehicle model is built in the three-dimensional software. The vehicle is simplified to ensure the smooth progress of the calculation. The three-dimensional model of the simplified vehicle is imported into the finite element analysis software. A finite element analysis vehicle model is built. The displacement and stress distribution of the frame are analyzed when the vehicle is under the torsional condition, the braking condition and the turning condition. The analysis results show that the frame can meet the design requirements under the three typical working conditions. 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.

Key words: Electric Sanitation Vehicle; Frame; Statics Analysis; Finite Element Analysis

I. Introduction

With the increase of the city scale, the number of urban garbage is increasing. The sanitation vehicle is an important equipment in the urban sanitation work. The sanitation vehicle is used not only to improve the efficiency of sanitation work, but also to reduce the work intensity of the sanitation workers. As the fuel vehicle is replaced by the electric vehicle, the electric sanitation vehicle has got people's attention. The light electric sanitation vehicle has the advantages of small size, no pollution and low noise, which has become the development direction of the future sanitation vehicle. The frame is the basis of the entire vehicle, and the reliability of the frame performance directly affects the driving safety and service life of the vehicle [1-4]. When the vehicle runs under the different working conditions, the force of the frame is very complicated [5]. It is difficult to avoid stress concentration by using the empirical formula to design and strength the frame [6]. More accurate result is obtained by the static analysis of the frame using the finite element method [7].

This research aims at the light electric sanitation vehicle frame. The vehicle model is built and simplified in the three-dimensional software. The three-dimensional model of vehicle is imported into the finite element analysis software. The finite element analysis model is built in the finite element analysis software. Through static analysis, the displacement and stress distribution of the vehicle are obtained under the torsional condition, the braking condition and turning condition. The frame is checked under the three typical working conditions.

II. Typical Working Conditions & Boundary Conditions

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 the safest in the four typical working conditions. Therefore, this study only analyzes the torsional conditions, the braking condition and the turning condition.

The torsional condition is a condition in which the frame is subjected to asymmetric support when the full-load vehicle is running on an uneven road. At this time, one rear wheel of the vehicle is at the road pit, and the wheel is in a state of being suspended. The braking condition simulates the situation of a full-loaded vehicle during emergency braking. At this time, the wheels are braked and the vehicle are subjected to an inertial force in the travel direction of the vehicle. The turning condition simulates the force of the frame when the fully loaded vehicle is turning. The lateral load is generated by the lateral centrifugal force of the vehicle.

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 Fig.1. Table 1 shows the corresponding boundary conditions imposed on the model according to the three typical working conditions.

Working conditions	Boundary conditions
Torsional condition	Left front wheel X, Z translation; right front wheel X, Y, Z translation; right rear wheel Y, Z translation
Braking condition	Left front wheel X, Y, Z translation; right front wheel X, Y, Z translation; left rear wheel Y, Z translation; right rear wheel Y, Z translation
Turning condition	Left front wheel Y, Z translation; right front wheel Y, Z translation; left rear wheel X, Y, Z translation; right rear wheel X, Y, Z translation

Table 1: Boundary Conditions under the Three Typical Working Conditions

III. Establishment of Geometry Model & Finite Element Model

The light electric sanitation vehicle without the cab to be analyzed is shown in Fig.1. 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. The simplified vehicle model is shown in Fig.2.

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The frame model is built as a whole. 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. Driver, the cab is replaced by three boards. These three boards are called pedal, seat front plate and seat rear plate respectively. The garbage, the garbage box and the lifer are simplified to the box plate. The front axle, the two front wheels are simplified to the two leaf spring pedestals and leaf spring models in front of the vehicle. The front axle, the two rear wheels and the motor are simplified to the two leaf spring pedestals and leaf spring models behind the vehicle. The battery is simplified as a rectangular body.

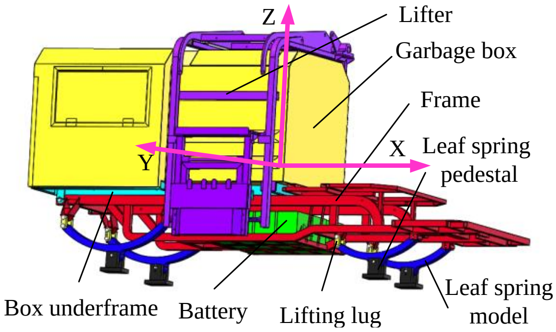

Fig. 1: Whole Vehicle Model without the Cab

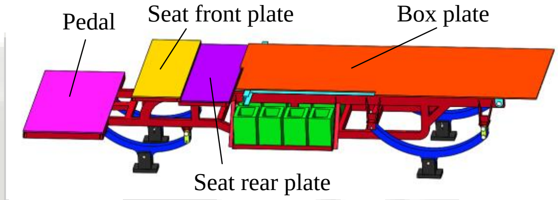

Fig. 2: Simplified Whole Vehicle Model

The model material parameters are defined according to the specific parameters of the equivalent model and the physical model. The model material parameters include the Poisson's ratio, the modulus of elasticity and the density of the material. According to the actual situation, the corresponding constraints and contact types are added to the vehicle model.

If the equivalent model is used instead of the real model, it is inconsistent with the actual situation when analyzing the turning condition and the braking condition, so it needs to be corrected. As can be seen from the force translation diagram shown in Fig.3, the effect of force F is the same as that of F_1 and M_e.

When the vehicle is under the turning condition and braking condition, the cab, the garbage box, the lifter and the garbage are subject to an inertial force F. The simplification of the model leads to the lowering of the mass center of the cab, the carriage, the lifter and the garbage. Compared with the effect of the force F, there is a lack of a torque M_e. Therefore, it is necessary to add a corresponding couple when analyzing the turning condition and the braking condition. This can be expressed as

$$M_e = Fd_z = Mad_z \qquad (1)$$

Where M_e is the couple that needs to be added, F is the inertial force of the equivalent model, d_z is the movement distance of the mass center along the Z axis, a is the acceleration of the vehicle, and m is the mass of the equivalent model.

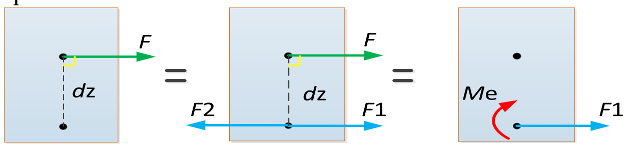

Fig. 3: Force Translation

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 7850 kg/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. The foot plate density is 10103 kg/m^3; the driving seat plate density is 43487 kg/m^3; the front leaf spring density is 6986 kg/m^3; the back seat plate density is 10667 kg/m^3; the carriage plate density is 110434 kg/m^3; the front leaf spring bed density is 11544 kg/m^3; the rear leaf spring density is 9191 kg/m^3; the rear leaf spring bed density is 11248 kg/m^3; and the battery pack density is 5342 kg/m^3.

According to the national standard, the vehicle is subjected to an acceleration of 4.5 m/s^2 in the negative direction of the X-axis and a centripetal acceleration of 0.3 g along the negative direction of the Y-axis to simulate the turning condition. The design safety factor of the frame under the three typical working conditions is 1.5.

The mass of the equivalent model, the acceleration, the distance of between the equivalent model mass center and the real model mass center in the Z-axis direction are substituted into Equation (1) to find the couples that need to be added under the turning condition and the braking condition. The size and application position of the applied couple are shown in Table 2.

IV. FRAME STATIC ANALYSIS

The frame is analyzed under the full-load torsion condition. When the vehicle is under the full-load torsion condition, the stress and displacement cloud diagrams of the frame are as shown in Fig.4. The maximum displacement of the whole vehicle is 5.845mm, which appears in the left rear corner of the frame. The maximum stress of the vehicle is 120.59 MPa, which appears at the bend of the lower longitudinal beam on the right side of the frame. Since the left rear wheel is suspended and the frame is squeezed by the chassis of the vehicle, there is a large displacement in the left rear corner of the frame without support. Therefore, it is reasonable that the maximum displacement occurs at the left rear corner of the frame.

Couple position	Physical mass (kg)	Mass center declining height (m)	Couple under the turning condition (N.m)	Couple under the braking condition (N.m)
Foot plate	86	1.018	257.39	393.97

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Driving seat plate	52	0.718	109.77	168.01
Back seat plate	52	0.748	114.35	175.03
Carriage plate	2795	0.493	4051.90	6201.80

Table 2: Couple & Corresponding Position

Since the left rear wheel is suspended and the weight of the rear half of the vehicle is absorbed by the right rear wheel, it is reasonable that the maximum stress appears on the right side of the frame. The front leaf spring of the frame is connected to the lower longitudinal beam of the frame, and the rear leaf spring of the frame is connected with the upper longitudinal beam of the frame. In addition, the battery frame is mounted on the lower longitudinal beam, and the bending of the lower longitudinal beam is prone to stress concentration. Therefore, it is reasonable that the maximum stress of the frame appears at the bend of the lower longitudinal beam on the right side of the frame. The safety factor of the frame is 2.28, which is greater than the safety factor of 1.5, so the results of the stress analysis are reasonable.

The frame is analyzed under the full-load braking condition. When the vehicle is under the full-load braking condition, the stress and displacement cloud diagrams of the frame are as shown in Fig.5. The maximum displacement of the whole vehicle is 4.501mm, which appears in the right front corner of the frame. The maximum stress of the vehicle is 88.81 MPa, which appears in beam 3.

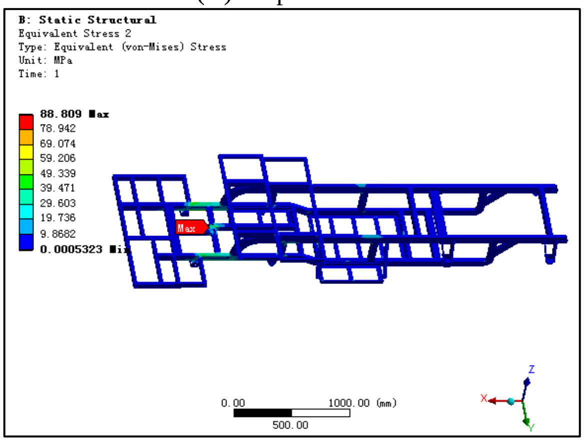
(A) Displacement

(B) Stress

Fig. 4: Displacement & Stress under the Full-Load Torsion Condition

When the front wheel of the vehicle is braked, the whole vehicle moves in the direction of travel under the action of the inertial force, so the entire frame has a certain displacement. Because there is a lifter installed on the right side of the compartment, the inertial force on the right side of the compartment is greater than the inertia force on the left side of the compartment when the vehicle is braked. The garbage box is fixedly connected with the box underframe, the box underframe and the rear of the frame are connected by a pin shaft, so that the frame is subjected to the bending moment formed by the inertial force due to the pin connection. This makes the force on the right side of the frame larger than the force on the left side of the frame, and thus the right front end of the frame is lifted up. Therefore, it is reasonable that the maximum displacement appears on the right front of the frame. Since the garbage box, the garbage and the box underframe are relatively heavy, it is subjected to a large forward inertial force when the vehicle brakes, which causes the frame to subject to a bending moment. Therefore, it is reasonable to have a large stresses at the two lower longitudinal beams and beam 2. The safety factor of the vehicle under the full load braking condition is 3.1, which is greater than the safety factor of 1.5, so the stress analysis results are reasonable.

(A) Displacement



(B) Stress

Fig. 5: Displacement & Stress under the Full-Load Braking Condition

The frame is analyzed under the full-load right turn condition. When the vehicle is in the full-load right turn condition, the stress and displacement cloud diagrams of the frame are shown in Fig.6. The maximum displacement of the frame is 1.359 mm, which appears in the right front

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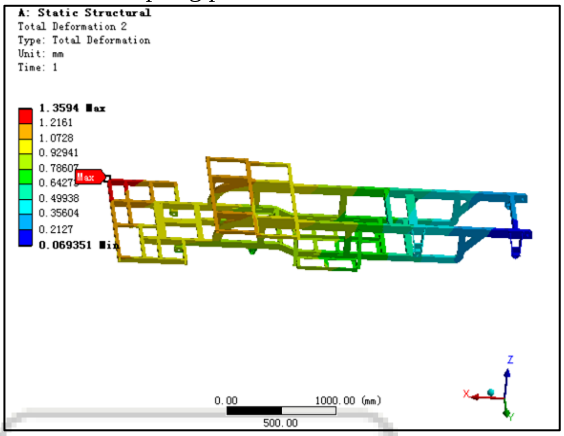
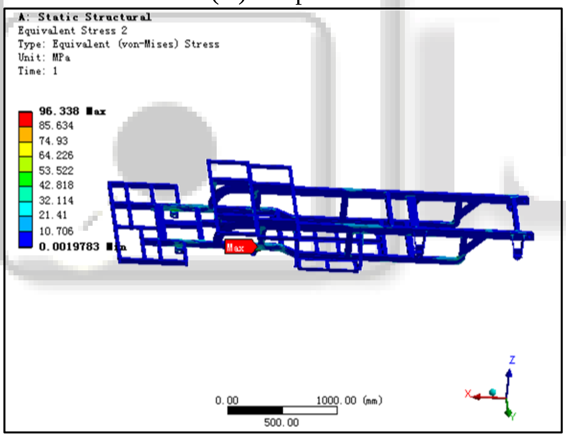
corner of the frame. The maximum stress of the vehicle is 96.34 MPa, which appears at the junction of the left front leaf spring and the frame. When the full-loaded vehicle is in the right turn condition, the ground gives the wheel a rightward force, and the whole vehicle receives a leftward inertial force. Therefore, the whole vehicle is subjected to a bending moment in the negative direction of the X-axis, and the displacement of the right side of the frame is larger than the displacement of the frame side. The distance between the front of the frame and the front leaf spring pedestal is farther than the distance between the rear part of the frame and the rear leaf spring pedestal.



(A) Displacement



(B) Stress

Fig. 6: Displacement & Stress under the Full-Load Right Turn Condition

Therefore, the rigidity of the front part of the frame and the rigidity of the rear part of the frame are small, so the displacement of the front part of the frame is large. It is reasonable that the maximum displacement of the frame appears in the right front corner of the frame. Under the full-load right turning condition, the inertia force of the vehicle will produce a bending moment, which causes the force on the left side of the frame to be greater than the force on the right side of the frame. Therefore, it is reasonable that the maximum stress appears on the left side of the frame. Since the front leaf spring and the lower longitudinal beam of the frame are connected by two plates, it is reasonable that the maximum stress occurs at the left front leaf spring. The safety factor of the full-load brake condition is 2.85 greater than the design requirement of 1.5, so the stress analysis results are reasonable.

V. CONCLUSIONS

The finite element method is used to analyze the mechanical properties of the frame. The three-dimensional model of the vehicle is modeled in the three-dimensional software. The three-dimensional model of vehicle is simplified to ensure the smooth progress of the calculation. The simplified vehicle three-dimensional model is imported into the finite element analysis software. The constraints, forces and moments are added to the model according to the actual situation and the force translation. A finite element model of the vehicle is built. The displacement and stress distribution of the frame are analyzed under the torsional condition, the braking condition and the turning condition. The analysis results show that the safety factor of the frame under the three typical working conditions is greater than the predetermined design safety factor, so the strength of the frame meets the design requirements.

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