Analysis of Strength Stiffness and Modes for Bus Body Frame

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Abstract: In this paper, the bus body frame is made as a research object. The finite element model of bus body frame is built in Hypermesh software. The static strength and stiffness of bus body frame under four typical working conditions are calculated by Nastran solver. Modal analysis is carried out by Lanczos method, low natural frequency and vibration mode are obtained. The analysis of results show that the strength and stiffness of bus body frame must meet design requirement, and the modal frequency is also within the design range. According to finite element analysis, the development cycle of new product is reduced, and theoretical basis for later model improvement and optimal design is provided.

1. Introduction
The body frame is the key component of passenger car. In addition to sufficient strength and stiffness, it must also have good comfort [1]. The body design directly affects the life, cost and safety performance of the bus. Therefore, it occupies a dominant position in the development of new vehicle. Many scholars have used finite element analysis to study the static characteristics of the body structure [2]. So it is very important to analyze the dynamic and static characteristics of the body frame.

This paper uses virtual simulation technology to establish finite element model of bus body frame. Four typical working conditions which are level bending, limiting torsion, sudden swerve and emergency brake are analyzed. The static strength and stiffness are obtained. Modal analysis on the bus skeleton is performed to calculate low-order natural frequency and mode shapes. It provides a theoretical basis for the later optimization design.

2. Simulation models and methods
According to the two-dimensional CAD drawings, the three-dimensional model of the bus body frame is built in Solidworks. The step format file is exported through its output interface. The bus body frame is meshed by Hypermesh software. The finite element model of bus body frame is established.

In the case of guaranteed calculation accuracy, according to the strength and stiffness of each part, the geometric model is simplified. Some non-bearing parts, functional parts, the body skin, all fillet and partial holes are deleted. The cross section of some parts is simplified. Most of the parts on the bus skeleton are stamped from thin plates. So the dimensions in the thickness direction are generally much smaller than other directions. Shell elements can be used for description it. The shell elements have better effects in handling bend deformation [3]. The mesh size is 15mm. the total elements are 407779. The total nodes are 437961. The triangle mesh is 1956 which meets the accuracy requirements. The
FEA model of the body frame is shown in Fig 1.

The main material of the body frame is Q235. The frame material is T52. The material of various warehouse sealing plates is Q195. The material of reinforcement is Q235.

The load of the bus body frame consists of four parts.

1. The mass of bus body is calculated by the density of the material and acceleration of gravity.
2. Body skin, glass, bus interior parts, luggage and luggage racks are simulated by mass element. It is applied to the corresponding position of the body structure in a distributed form.
3. The mass of each chassis assembly applies mass element at its center of mass. The mass which form is RBE3 evenly distributes on the corresponding nodes of the body structure.
4. The mass of passengers and seats are distributed on frame and chassis through mass element.

The mass of the main components is shown in Table 1.

| Name                                | Mass/kg |
|-------------------------------------|---------|
| Powertrain                          | 940     |
| Transmission shaft + steering wheel | 44.2    |
| Tank                                | 188.5   |
| Warehouse doors and accessories      | 190     |
| Luggage compartment seal plate      | 120     |
| Body skin                           | 348     |
| Floor + glass+ wind tunnel + interior + air condition | 2515 |
| Passenger+ hand-held luggage         | 2816    |
| Total mass                          | 9756.3  |

The load of level bending and limiting torsion are nonlinear in actual driving. Therefore, the dynamic load factor should be considered in the analysis. The level bending mainly simulates the stress and deformation of the bus when the bus is driving on the highway at a constant speed [4]. The limiting torsion mainly simulates larger torsion of the bus body when the bus is driving on an uneven road with potholes. The sudden swerve simulates the situation of bus sharp turning when it is driving. The emergency brake simulates the maximum braking force which is applied to the front and rear wheels at the same time. It mainly tests the local structural strength of the thrust rod and the guide arm connecting area [5].

The boundary conditions of four typical working conditions are shown in Table 2.

| Working condition name | Load | Boundary condition |
|------------------------|------|--------------------|
| Level bending          | 1.3g-z | Left front wheel: Dof2, Dof3 Left rear wheel: Dof2, Dof3 Right front wheel: Dof2, Dof3 Right rear wheel: Dof2, Dof3 |
| Limiting torsion       | 1.3g-z | Dof1, Dof2, Dof3 | Dof1, Dof2, Dof3 | Dof1, Dof2, Dof3 |
| Sudden swerve          | g-z, 0.4g-y | Dof1, Dof2, Dof3 | Dof2, Dof3 | Dof1, Dof3 |
| Emergency brake        | g-z, 0.7g-x | Dof1, Dof2, Dof3 | Dof1, Dof2, Dof3 | Dof1, Dof3 |

Explanation: The FEA coordinate system is consistent with the bus coordinate system. 1.3g-z
means 1.3 times of gravity in z axis. 0.4g-y means 0.4 times of gravity in y axis. 0.7g-x means 0.7 times of gravity in x axis. Dof1 means x axis movement. Dof2 means y axis movement. Dof3 means z axis movement.

3. Results and discussion

Figure 2 shows the stress and the displacement of the body frame under level bending condition. It can be seen from the figure 2(a) that the maximum Von. Mises stress appears on the lower beam of the frame. The value is 143.5 MPa. Its material is Q235. The permissible stress is 160 MPa. It meets the strength requirements. The high stress area is mainly concentrated in the middle and rear part of the frame. The main reason is that the engine and gearbox of the bus are located in this area. It can be seen from the figure 2(b) that the maximum vertical displacement is located at the junction of luggage compartment, engine and gearbox. The value is 3.00 mm. It is smaller than the reference value of similar models in the statistical data. So it has a larger overall bus stiffness margin.

![Figure 2: Level bending condition analysis result](image)

Figure 3 shows the stress and the displacement of the body frame under limiting torsion condition. It can be seen from the figure 3(a) that the maximum Von. Mises stress appears on the frame beam and luggage compartment. The value is 180.6 MPa. Its material is T52. The permissible stress is 270 MPa. It meets the strength requirements. It can be seen from the figure 3(b) that the maximum displacement is located at the left wind window of dash. Its value is 14.69 mm. It is caused by the suspension of the left front wheel. The value of enterprise standard is 20 mm. It meets the stiffness requirements.

![Figure 3: Limiting torsion condition analysis result](image)

Figure 4 shows the stress and the displacement of the body frame under sudden swerve condition. It can be seen from the figure 4(a) that the maximum Von. Mises stress appears on the frame. The value is 139.8 MPa. Its material is T52. It meets the strength requirements. It can be seen from the figure 4(b) that the maximum displacement is located at air conditioner installation place of headliner. Its value is 10.57 mm. When bus turns sharply to the right, the overall body frame deviates to the left. So headliner undergoes a large lateral displacement. It tests the stiffness of the body frame design.

![Figure 4: Sudden swerve condition analysis result](image)

Figure 5 shows the stress and the displacement of the body frame under emergence brake condition.
It can be seen from the figure 5(a) that the maximum Von. Mises stress appears on the reinforcement connecting plate. The value is 110.5MPa. Its material is Q235. It meets the strength requirements. It can be seen from the figure 5(b) that the maximum displacement is located at reinforcement connecting plate. Its value is 6.09mm. It meets the stiffness requirements.

![Bus Body Frame Stress](image1)
![Bus Body Frame Displacement](image2)

(a) The stress of bus body frame  (b) Magnitude displacement of bus body frame

Fig 5 Emergence brake condition analysis result

The modal analysis of the bus is carried out under free boundary conditions. For complex models, Higher-order mode shapes have less influence on the dynamic response of the model. Therefore, the modal analysis extracts the results of the first ten elastic body modes. The first ten natural frequencies and vibration modes of the body frame are shown in Table 3.

| Order | Frequency/Hz | Displacement/mm | Mode shape description       |
|-------|--------------|-----------------|------------------------------|
| 1     | 8.02         | 1.92            | Back wall torsion            |
| 2     | 8.50         | 1.64            | First-order vehicle torsion  |
| 3     | 13.52        | 2.25            | Second-order vehicle torsion |
| 4     | 14.3         | 1.91            | First-order vehicle Y bending|
| 5     | 15.28        | 2.32            | First-order headliner bending|
| 6     | 15.98        | 4.01            | Second-order headliner bending|
| 7     | 20.52        | 1.95            | Second-order vehicle Y bending|
| 8     | 20.71        | 3.91            | Third-order headliner bending|
| 9     | 21.10        | 2.12            | Bending and torsion combination|
| 10    | 21.63        | 2.45            | First-order vehicle Z bending|

When the bus is running on the highway, the external excitation mainly comes from road unevenness. According to relevant information, the highest frequency of road excitation is 2-5 Hz. Engine excitation is another important source of external excitation. The idling speed of the engine is usually 600~800 r/min, and the vibration frequency is usually 30~40 Hz. The first ten-order natural frequency of the bus ranges from 8.02 Hz to 21.63 Hz, so resonance will not occur.

4. Conclusions

Through the analysis of four typical working conditions of the body frame, it can be known that the maximum stress and displacement appear in the limiting torsion. Their value is less than the design requirements. There are large strength and stiffness margin for optimization. Through modal analysis, the first ten modal frequencies and vibration shapes of the vehicle are obtained. Comparing it with the excitation frequency of the road surface and the engine, it can be seen that when the bus is driving will not produce resonance phenomenon. It provides a reference for the optimization design of vehicle.

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