Influence of Bearing Structure Parameter Changes on Vehicle Modal Characteristics

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Abstract. It is known that vehicle structural thickness change will lead to vehicle modal characteristics change .In this paper, the thickness of floor, sidewalls and vehicle top are chosen as the variables so as to calculate the relationship amongst thickness change and frequencies (Vertical bending- f_1, Torsion- f_2, Rhombus- f_3),vertical nodes and the ratio of Vertical bending and Torsion respectively. The results show that structure size have a significant impact on the vehicle body natural frequency; In terms of the overall degree of influence, the vehicle top and vehicle top corrugated board have greater influence on *f1, f2, f3* than the other size's; For a given vehicle, in the premise of no significant increase in vehicle body weight, we can increase the natural frequencies *f1, f2, f3* by adjusting the dimensions of the material. Also we can change the vehicle body vertical bending nodes by adjusting the component dimensions, and increase the thickness of the vehicle top to improve the ratio of vehicle body vertical bending and torsion, and reduce the ratio of vehicle body vertical bending and torsion by increase the floor, sidewall thickness. But how the floor thickness affect the ratio of vertical bending and torsion depends on thickness which has been designed.

Introduction

With the increasing train speed, the vertical, longitudinal, lateral and tensional excitation which is loaded on the train in operation is increasing [1].On the other hands, because of the application of lightweight train design[2],following with reducing natural frequency, this leads to the train generates more vibration . This will not only reduce the ride comfort, but also it will affect the service life of the structure.

The thickness of the body structure change will lead to changes in the stiffness and mass of [3], the deformation stiffness of the control structure of the vehicle body (deflections), the stability and natural frequency. The thickness of the body structure change will lead to changes in the stiffness and mass [3]. And the stiffness of the body controls the structure deformation, stability and natural frequency of the vehicle body.

The Vehicle Body Finite Element Model and the Choose of Design Variables

The Vehicle Body Finite Element Model

The geometric model was divided into meshes by HYPERMESH [4].In this paper the vehicle model was dispersed with SHELL63 elements. The vehicle was divided into 661979 units and 501639 nodes. The real constant of each part of the vehicle body was defined according to the actual thickness parameters. The finite element model of vehicle body is shown in figure 3.1.

The vehicle bearing structure was mainly composed of floor, sidewalls, vehicle top and end walls [5].In this paper, the floor of certain high speed vehicle was mainly established by spandrel beam,

traction beam, the corrugated floor and the air guide etc... The spandrel beam edge that is the longitudinal beam on the left and the right of the floor and is the key components of connecting the floor and side wall. The corrugated floor is made of the extrusion-shaped aluminum. Also the reinforced frame is added in the longitudinal direction in order to enhance the longitudinal strength of the floor (Figure 3.2).In the calculation we ignore the structure dimension part which has few effect, and only consider the effect of corrugated floor on modal characteristics of the vehicle body.

For the sidewalls, we only modify the thickness of inner sidewalls and corrugated board because of considering the limiting width through body design throughout the calculation. The model of the sidewalls is shown in figure 3.3. The vehicle top is composed of flat, round top and other structures, and the main components are butted, installed and welded using the same large-scale hollow extruded shape welded splice. In the analysis, we only consider the influence of the thickness of flat part and the corrugated board on the body modal characteristic. Because of the vehicle gauge and other factors, we only consider the effct of thickness of inner sidewalls. The model of vehicle top is shown in figure 3.4.
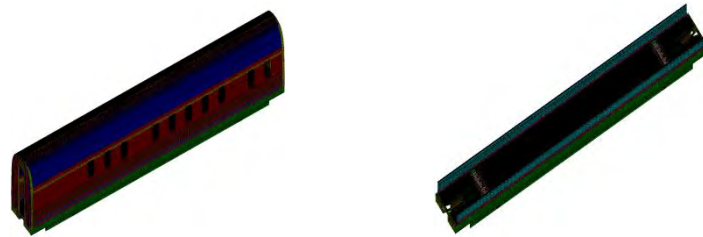

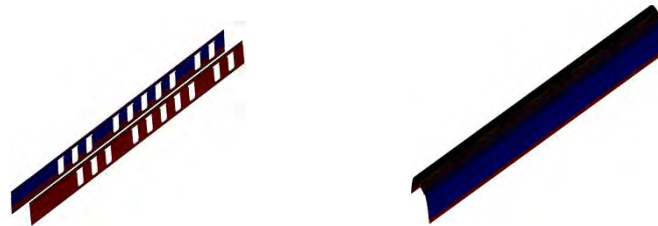Fig.3.1 Vehicle Body Finite Element Model Fig.3.2Floor Model

Fig.3.3 Sidewalls Model   Fig.3.4Vehicle Top Model

The Choose of Design Variables

We make modal analysis and calculation for the vehicle using the Block Lanczos method in ANSYS [6], and extract the natural frequency and mode of vibration within the 30Hz.in order to guarantee the effectiveness of the model, we compare the calculate result and experimental results. The results are shown in table 3.1.

Tab. 3.1 Calculation and Experimental Results

Orders	Calculation Frequencies[Hz]	Experimental Frequencies [Hz]	Modal shapes	Errors[%]
1	21.631	21.2	Vertical bending	2.0
2	22.967	22.8	Rhombus	0.7
3	38.115	38.0	Torsion	0.3

The original thickness of the floor is 2.5mm.In the original design model, the inner and outer side floor have the same thickness. So the range of the thickness of the selected floor d1 is from1mm to5.5mm. The range of the thickness of inner side d3 is from1.5mm-6mm. The inner thickness range of the vehicle top d5 is from1mm to5.5 mm .All the corrugated boards have the same thickness (1.8mm)and their range of thickness are all from 1mm to 3mm. Calculation condition table as shown in Table 3.2.

Tab. 3.2 Calculation Condition

Material location	d-1.5	d-1	d-0.5	d	d+0.5	d+1	d+1.5	d+2	d+2.5	d+3
Floor (d_1)[mm]	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5
Sidewall (d_3)[mm]	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6
Vehicle top (d_5)[mm]	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5
Corrugated sheet	d-0.8	d-0.6	d-0.4	d-0.2	d	d+0.2	d+0.4	d+0.6	d+1	d+1.2
(d_2, d_4 ,d_6)[mm]	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.8	3

The Calculate Effect Result of Structural Parameters Change on Modal Characteristics

The Effect of Bearing Structural Parameters on Modal Frequencies

By finite element calculation, the influence of vehicle body structural parameters on vertical bending, torsion and rhombus frequencies outcome as shown in Fig.4.1, 4.1 and 4.3 respectively.
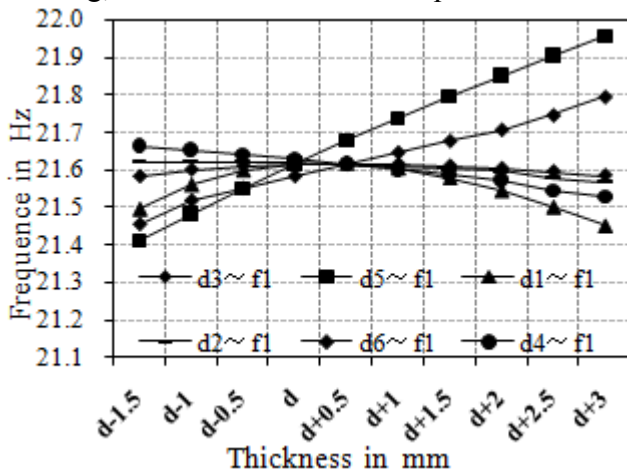

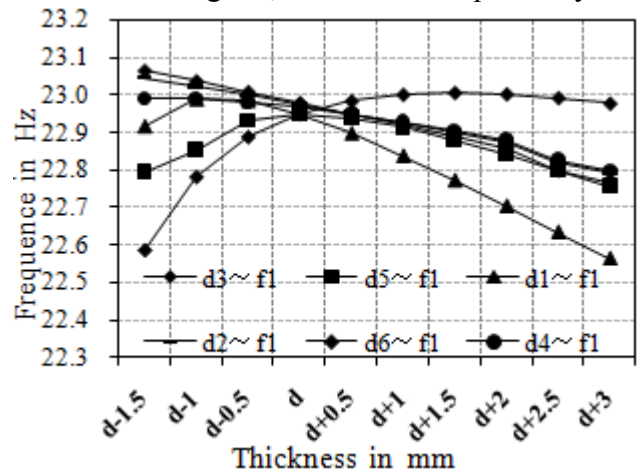Fig.4.1 The Relationship between Material Thickness and Vertical Bending Frequencies

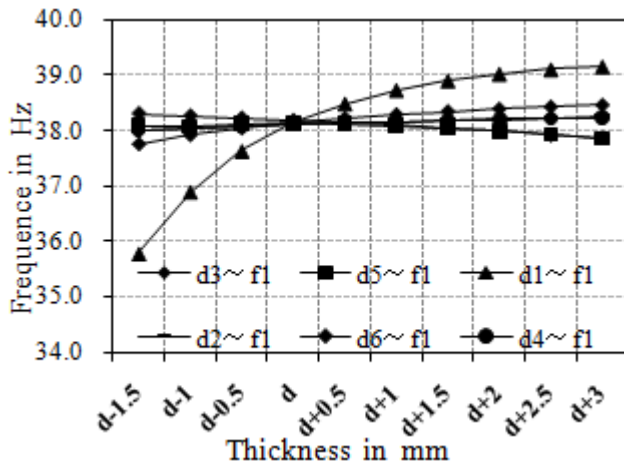Fig.4.2 The Relationship between Material Thickness and Rhombus Frequencies

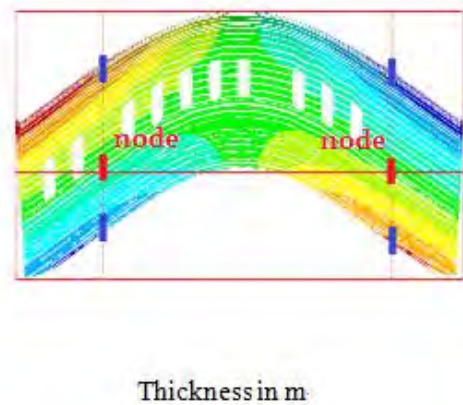Fig.4.3The Relationship between Material Thickness and Torsion Frequencies

Fig.4.4 The Vehicle Body Vertical Bending Vibration Figure

Figure 4.1shows: The curve of top thickness ~ f1 has the largest gradient value. That is the vehicle top has the largest influence degree on f_1, followed by the top corrugated boards. It has little help to improve f_1 by increase the thickness of floors, the floor corrugated boards, the side walls and the sidewalls corrugated boards. But reducing the thickness of floor, sidewalls, vehicle top and top

corrugated boards will reduce f_1. And reducing the sidewalls and sidewalls corrugated boards will increase f_1.

Figure 4.2shows: Increasing the thickness of all boards will reduce the frequency of rhombus. The curve of sidewalls$\sim f_2$ has the smallest gradient value, the curve of floor$\sim f_2$ has the largest gradient value. Other material thickness has similar influence degree on the rhombus frequency. However, reducing the thickness of corrugated boards will increase the rhombus frequency, and reducing thickness of remaining material will reduce rhombus frequency.

Figure 4.3shows:the curve of floor$\sim f_3$ has the largest gradient value. That is the floor thickness has the largest influence degree on f_3.the remaining material has little influence on f_3.

The Influence of Bearing Structural Design Variables on Body Modal Shape

The fixed points on the vehicle body are named nodes when vehicle body vertical bending deformation of occurs. The position of nodes has particular importance on the hanging devices chosen and installation. The vertical bending mode shape is shown in Figure 3.4.

The research methods are as follows: First, selecting the nodes which has zero lateral and vertical displacement from the neutral plane in the calculation result and noting the node number and longitudinal position coordinates. Then select and node the zero-displacement nodes from other calculation condition results.

Finally, horizontal line is chosen to represents the undeformed equilibrium position, And choose the end and intermediate position nodes as the feature points to obtain schematic diagram of how the material thickness influence the vertical bending nodes.

The calculation result as shown in table4.1. Where l_1, l_2 denote the distance between each node and the vehicle body end.

Tab. 4.1Caculation Results

| Condition		x coordinate of left node	l_1	x coordinate of right node	l_2
d-1.5[m]	Floor	5.128	5.128	18.766	5.334
	Sidewalls	5.228	5.228	18.849	5.251
	Vehicle top	5.198	5.198	18.798	5.302
d-1[m]	Floor	5.152	5.152	18.799	5.301
	Sidewalls	5.224	5.224	18.850	5.25
	Vehicle top	5.202	5.202	18.807	5.293
d+1[m]	Floor	5.224	5.224	18.872	5.228
	Sidewalls	5.218	5.218	18.842	5.258
	Vehicle top	5.219	5.219	18.819	5.281
d+2[m]	Floor	5.257	5.257	18.892	5.208
	Sidewalls	5.209	5.209	18.843	5.257
	Vehicle top	5.223	5.223	18.825	5.275
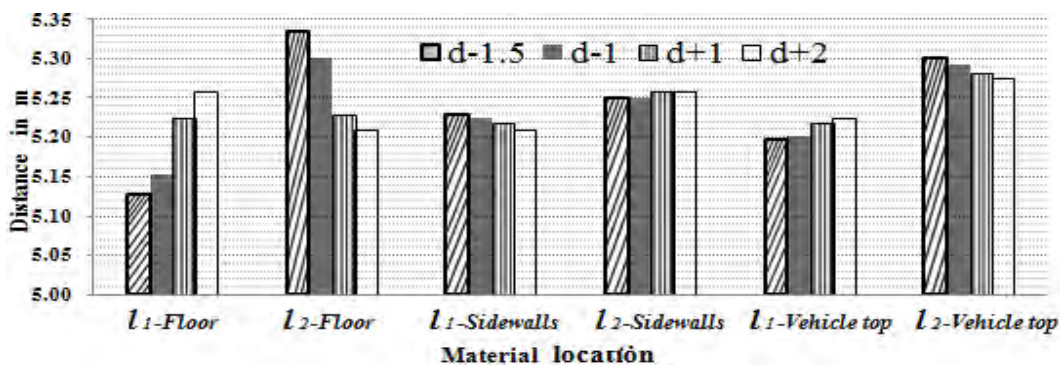
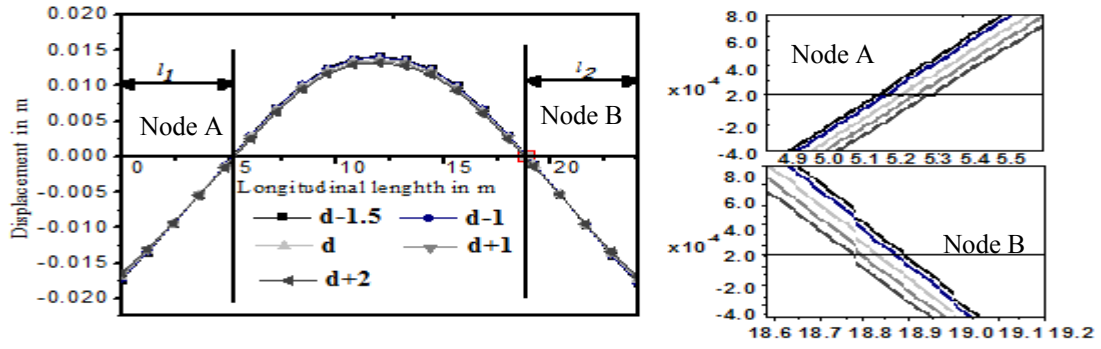Fig.4.4 The Trend Figure of Distance between Body End and Node

Fig. 4.5 The Effect of the Thickness of Floor on Vertical Bending Node Location of Vehicle Body and Its Nodes Thinning Curve

Figure 4.5 shows: with the increase of the inside floor thickness, vehicle body vertical bending nodes gradually move to the middle of car, and the right nodes move obvious to the lefts; Figure 3.6 shows: with the increase of the flank thickness, the left side nodes move to the left side of car, the location of right side node basically unchanged; Figure 3.7 shows: with the increase of the thickness of the roof, vehicle body vertical bending nodes gradually move to the middle of car, and the right nodes move obvious to the lefts.

The Influence of the Thickness of the Bearing Structure to the Ratio of Vehicle Body Bending and Twisting Frequency

The ratio of vehicle body bending and twisting frequency [7][8] is an important factor to take into account for car design, a rational design can effectively avoid coupled vibration caused by the two frequencies close too much, the lower the two frequencies, the smaller energy consumption for self-excited vibration, and more easily flutter; if the bending, twisting frequency closer,   not only the energy exchange turn more easily, but also easy to flutter. According to the results of the previous section, the empirical formulas about the relationship between the thickness of each bearing structure and the bending, diamond, torsion natural frequency and modal frequencies of the vehicle body by polynomial regression method are as follows:

$$A_1 = \frac{f_1}{f_3} = \frac{21.2965 + 0.0034\,d_1 - 0.0602\,d_1{}^2 + 0.25736\,d_1{}^3}{32.8345 + 0.0549\,d_1 - 0.763\,d_1{}^2 + 3.6913\,d_1{}^3}. \tag{1}$$

$$A_3 = \frac{f_1}{f_3} = \frac{21.4871 + 0.0011\,d_3 - 0.0185\,d_3^2 + 0.0889\,d_3^3}{37.0847 + 0.0048\,d_3 - 0.0837\,d_3^2 + 0.5591\,d_3^3}. \tag{2}$$

$$A_5 = \frac{f_1}{f_3} = \frac{21.2602 - 0.0072\,d_5^2 + 0.1587\,d_5^3}{37.9511 - 0.0363\,d_5^2 + 0.1553\,d_5^3}. \tag{3}$$

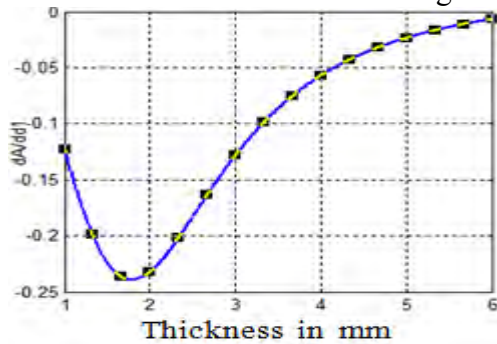The calculation results are shown in figure 5.1 to 5.3

Fig. 5.1 The Bending and Twisting Frequency Ratio Influenced by the Thickness of Floor
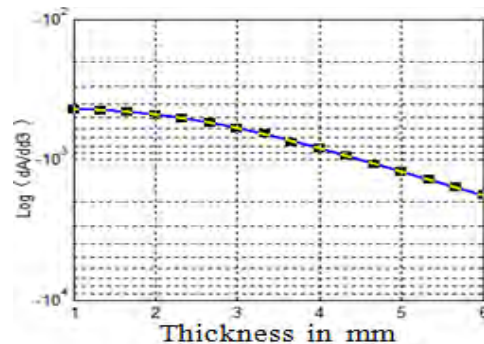
Fig. 5.2 The Bending and Twisting Frequency Ratio Influenced by the Thickness of Sidewalls
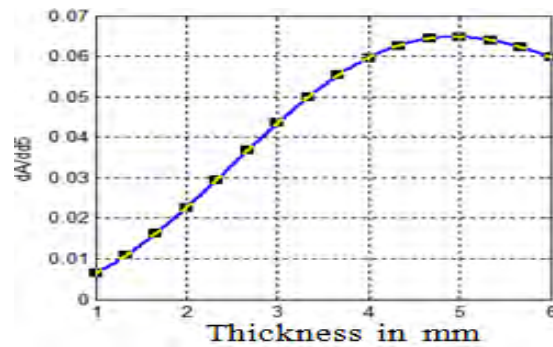
Fig. 5.3 The Bending and Twisting Frequency Ratio Influenced by the Thickness of Top

    Figure5.1 shows: the bending and twisting frequency ratio turn smaller with increasing of thickness; when the floor thickness less than 3mm, the ratio change rapidly with thickness. The ratio reach maximum when the thickness is 1mm.Figure 5.2 shows: with the increase in the thickness of the body sidewall, the bending and twisting frequency ratio decreases monotonically, and the reduced amplitude turn smaller.Figure 5.3 shows: the bending and twisting frequency ratio turn bigger with increasing the roof thickness; after the roof thickness greater than 4mm, the ratio to the roof thickness shows an approximate linear increasing trend.

Summary

Profile structure size has significant effect on the natural frequencies f_1, f_2, f_3 of vehicle body, In terms of the overall impact, the dimension of roof, roof of corrugated board and floor is greater than the influence of other sizes to f_1, $f2$, $f3$; for a certain vehicle body, under the premise without a significant increase the weight, it can adjust the size of the parts to improve the body's natural frequency f_1, f_2, f_3, and change the location of bending node; Increasing the roof thickness can improve the ratio of bending and twisting frequency, increase the floor, side wall thickness can reduce the ratio. But the influence of floor to the bending and twisting frequency ratio is decided on the thickness of it.

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