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Vibration Reduction Design of Equipment on the Low-floor Tramcar's Roof

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Abstract. In order to suppress the influence of the excitation source of the roof equipment on the vibration of the vehicle body, a vibration reduction design scheme based on rigid and flexible coupling dynamic model is proposed. The finite element model is established, and the finite element analysis is used to calculate the car body mode. The dynamic model is established and the vibration mode is analyzed. The frequency range of the equipment is determined by the analysis result which is based on the vibration reduction theory. The rigid and flexible coupling dynamics model is established to optimize the equipment support frequency. The results show that when the frequency of the equipment is 10 Hz, the support point can obviously eliminate the vibration effect. The dynamic deflection of the equipment is less than 2 mm, and the vibration performance satisfies the design requirements.

1. Introduction

Low floor tramcar belongs in transit traffic mode, with fast, convenient, safe advantages, which also save energy and investment, protect the environment. So low floor tramcar is very suitable for arterial traffic of small and medium-sized cities and artery traffic of large cities [1]. In this paper, the tramcar adopts a hybrid drive mode of super capacitor and fuel cell. The capacitor is omitted with this power supply method, which reduces the occupation of the urban space. But the fuel cell and heat sink need to be installed to the roof [2]. the equipment will influent the vibration of body [3-7]. At the same time, the equipment is excitation source. In this paper, a rigid-flexible coupling dynamics model is established to optimize frequency of the device.

2. Design considerations

The low floor tramcars are composed of three body modules. The center of each module is equipped with a bogie. The middle body module is the trailer, and the two side is motor car, which are group into Mc+TP+ Mc. The fuel cell and heat sink need to be installed to the roof of the middle car, which are shown in Figue.1. There are two pieces of fuel cell and a heat sink. A total of 12 installation points are built as shown in the figure1. The working frequency of the heat sink is shown in the table.1.

Table1. The working frequency of the heat sink.

Seasons	Commonly	Summer	Spring	Autumn
Working Frequency(Hz)	50	40	30	25

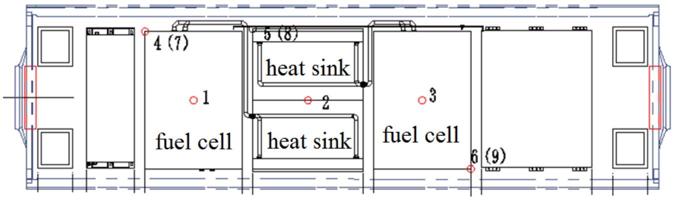

Figure 1. The fuel cell and heat sink of the roof.

In order to study the influence of the roof equipment, the model of three-module body is established. First, calculate the rigid body mode. Then establish the finite element model of the middle car. According to polycondensation calculation, a rigid-flexible coupling dynamics model is established. Then, study the influence of the roof equipment.

3. A rigid-flexible coupling dynamics model of car's body

In order to establish a rigid-flexible coupling dynamics model, the finite element model need to polycondensation calculation to improve the calculation efficiency. The polycondensation calculation follows the Guyana rule[8]. The points of polycondensation calculation are selected as figure.2.

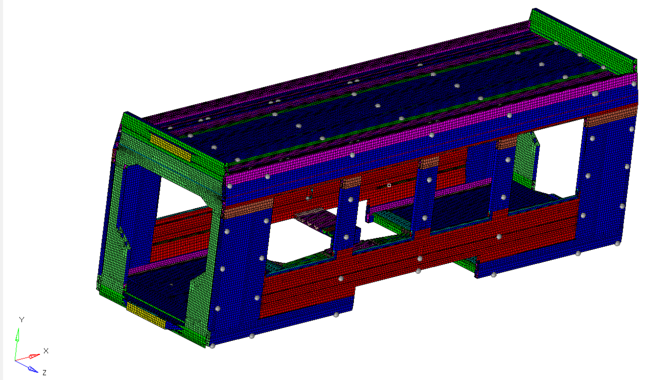

Figure2. The selected points of polycondensation calculation.

After the polycondensation calculation, the top nine lower-order modes are shown as the table2.the results have errors up to 3.58%, which explain the high accuracy of the polycondensation calculation. It is up to the standard of the establishment of dynamic model.

Table 2. The main lower-order modes of the car body

Oder	The finite element model /Hz	Polycondensation calculation /Hz	error/%
1	24.22	24.12	0.41
2	26.76	26.14	2.32
3	28.84	28.71	0.45
4	31.87	33.01	3.58
5	33.64	33.45	0.56
6	44.21	45.20	2.24
7	45.84	45.72	0.26
8	47.09	47.99	1.91
9	48.81	48.74	0.14

A fixed hinge and a hinge are set between car B and car C, which makes the body B, C in the vertical is rigid, only rotate around the z axis. Car A, B could rotate around the y axis.Based on the coordinate system, the SIMPACK model is established. According to the topology of the vehicle system, the hinge between the car bodies can be simulated by spring. The SIMPACK model is replaced with the car body of polycondensation calculation. Then the rigid-flexible coupling model is obtained as the figure.3.

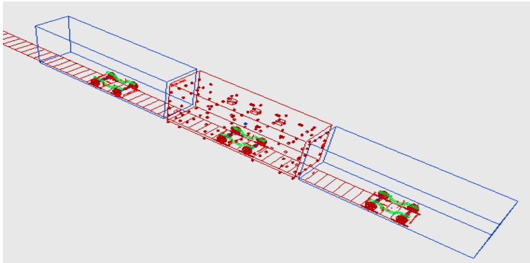

Figure3. Simpack multi-body dynamics model

In SIMPACK rigid body model, the body is linear. The vibration modes can be obtained as shown in the table3, there are six vibration mode of rigid body. The frequency of floating is 1.8988 Hz.

Table 3. The vibration modes

Oder	Shape	Frequency/Hz	Damping ratio /%
1	The rolling swing	0.452 8	9.64
2	Shaking of car A	0.472 2	63.48
3	Nod of car A	0.852 1	27.96
4	Traverse of car A & C	1.363 0	23.55
5	Floating	1.898 8	38.67
6	Floating of car A	1.928 1	29.78
7	Shaking of car A & C	2.058 0	9.48
8	The rolling swing	2.184 1	61.90

4. Vibration design theory and equipment frequency selection

According to the basic theory of vibration absorption designing, no matter how much damping ratio $\frac{C}{C_0}$, only when $\frac{\omega}{\omega_n} > \sqrt{2}$, the displacement transfer rate is less than 1. Therefore, in order to achieve the vibration isolation, the natural frequency of elastic support system $\frac{\omega}{\omega_n} > \sqrt{2}$ (condition 1); if the condition cannot be achieved, the natural frequency of elastic support system $\frac{\omega}{\omega_n} <$ 0.4[9,10](condition 2).

The body vibration is divided into rigid vibration and elastic vibration. According to the analysis, the rigid mode, the rigid body vibration gathers in 0~3 Hz. The lowest vertical frequency is 2.184 1 Hz. The overall vibration frequency is 2.1841 Hz. The body elastic vibration is above 24.22Hz without the roof equipment. There isn't body partial model under 24.22Hz.

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According to condition 1, $\omega_n < \frac{\omega_1}{\sqrt{2}}$, the first-order respiratory vibration frequency ω_1 is selected, $\omega_1 = 24.22$ Hz, then $\omega_n < \frac{\omega_1}{\sqrt{2}} = 17.13$ Hz.

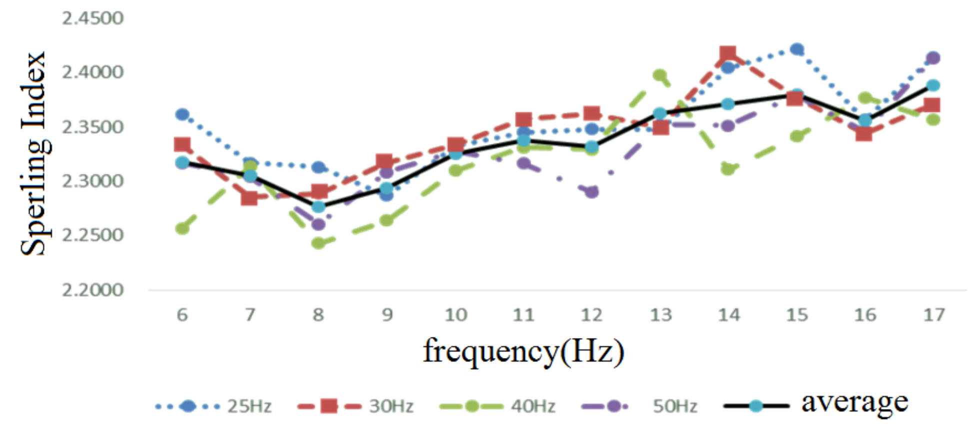
According to condition 2,$\omega_n > \frac{\omega_2}{0.4}$, the whole floatation vibration frequency ω_2 is selected, $\omega_2 = 2.184\,1$ Hz, then $\omega_n > \frac{\omega_2}{0.4} = 5.46$ Hz.

For passive isolation, it is better that the vibration isolation frequency is between 6 and 17Hz.

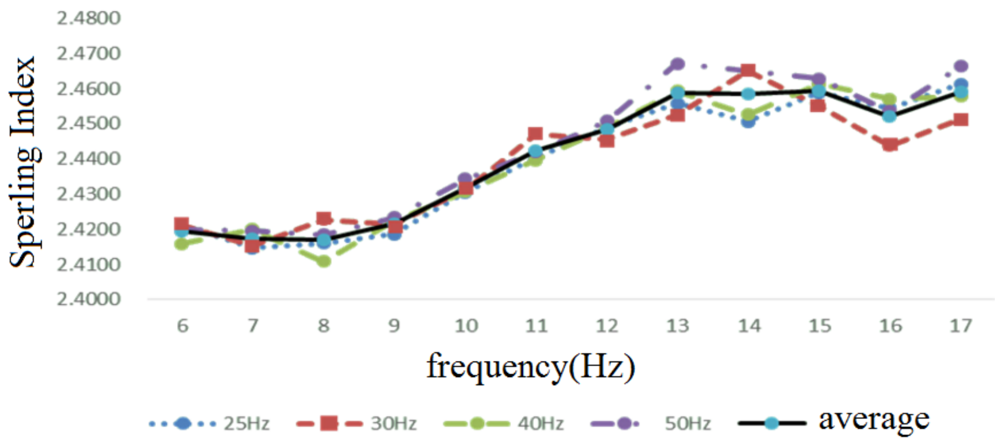
5. Optimization of device frequency

First, the Sperling indicator of intermediate car is selected as the basic evaluation index. For evaluating the vibration of the device, the acceleration RMS of three points is selected. As figure 1, number 1~3 is the center of the front fuel cell, radiator, and the final fuel cell. Number 1 point is selected to calculate transmissibility. Number 4~6 points are selected to calculate displacement. Applying three-way sine excitation achieves the influence of steady work of radiator to train. Each direction of excitation amplitude is set 200N.

As shown in figure.4, there is different lateral, vertical Sperling indicators under the different work of radiator. The result shows that the lateral, vertical Sperling indicators increase with the frequency increasing. When the device frequency is 8Hz, the Sperling index obtains the optimal value.



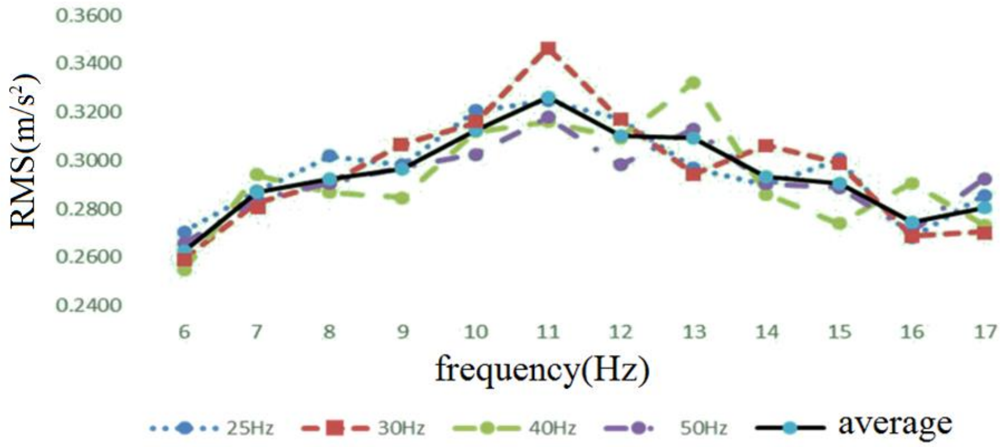
(a) Lateral sperling index



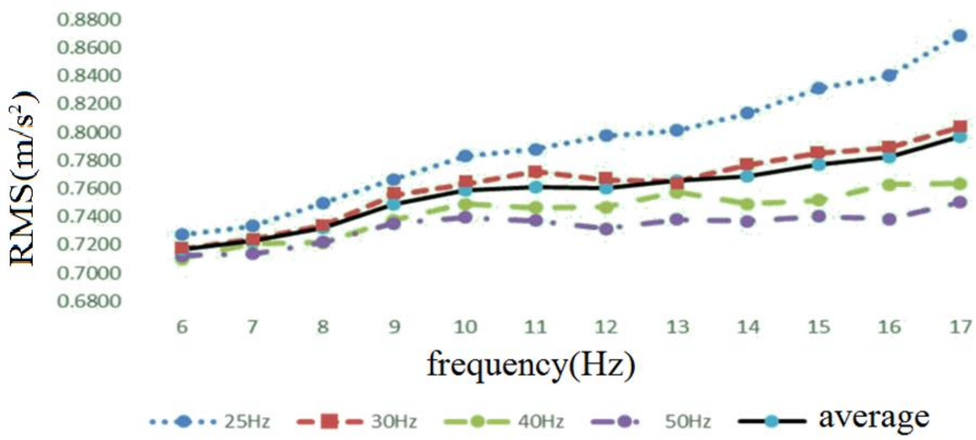
(b) Vertical sperling index

Figure 4. Sperling index of car body

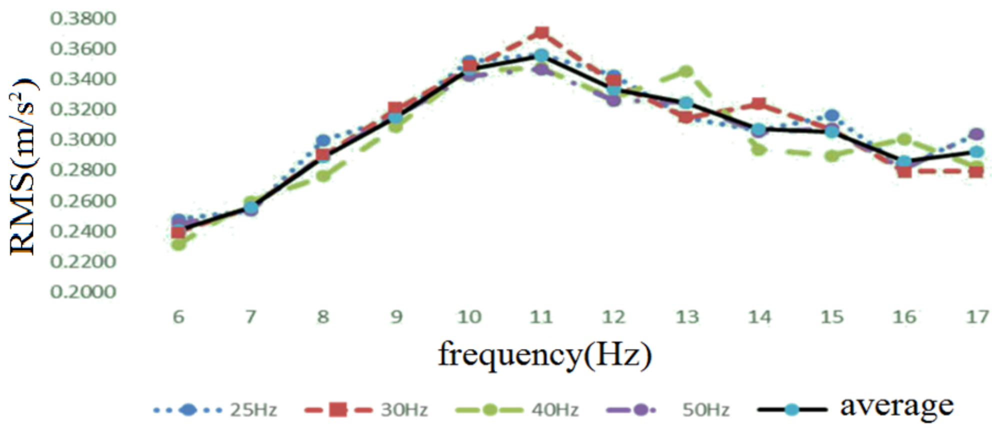
With the frequency changing, the 1~3 point's lateral acceleration RMS (root mean square) value is shown as figure.5. The lateral acceleration increases with the equipment frequency increasing under 11 Hz for point 1 to point 3. The lateral acceleration decreases with the equipment frequency increasing after 11Hz for point 1 and point 3. When the equipment frequency is 6 Hz, the lateral acceleration is the lowest. But The lateral acceleration increases with the equipment frequency increasing for point 2.



(a) The lateral acceleration rms value of point 1



(b) The lateral acceleration rms value of point 2



(c) The lateral acceleration rms value of point 3

Figure 5. The lateral acceleration rms value of point 1~3

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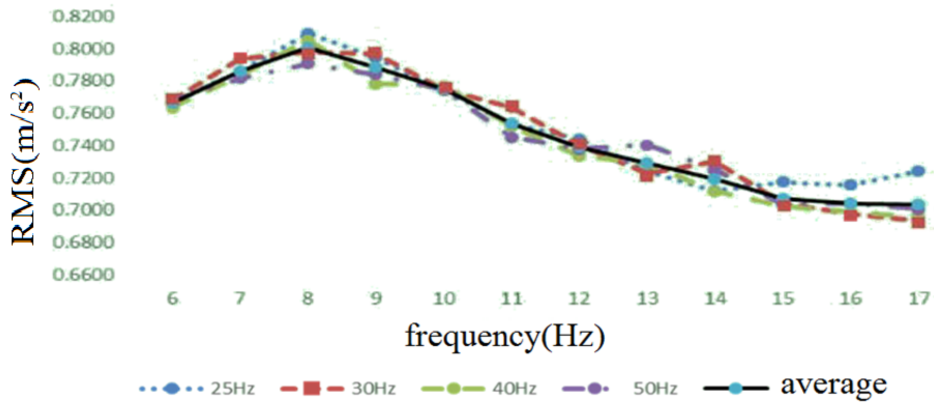
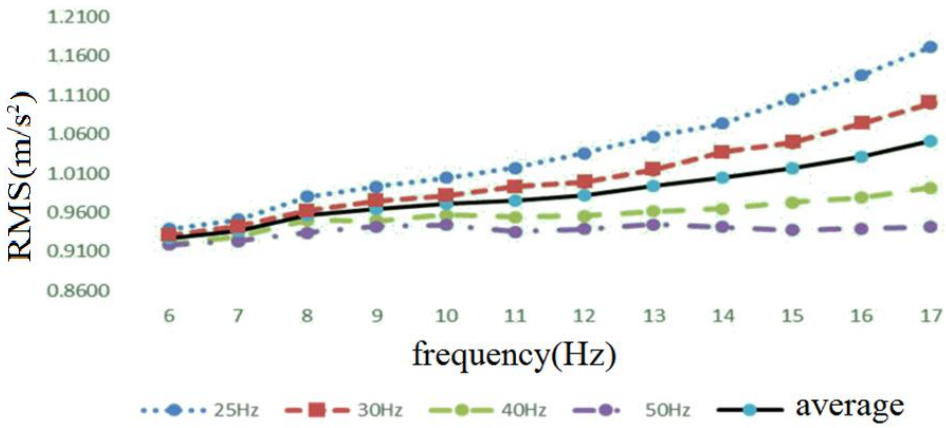
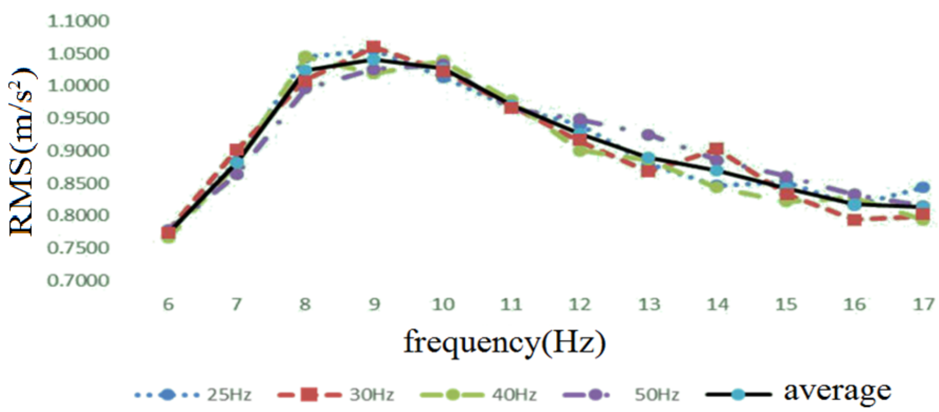
With the frequency changing, the 1~3 point's vertical acceleration is shown as figure.6. The vertical acceleration increases, then decreases with the equipment frequency increasing under 11Hz for points 1~ 3. When the equipment frequency is 17 Hz, the vertical acceleration is the optimal value. But the vertical acceleration increases with the equipment frequency increasing for point 2.



(a) The vertical acceleration rms value of point 1



(b) The vertical acceleration rms value of point 2



(c) The vertical acceleration rms value of point 3

Figure 6. The vertical acceleration rms value of point 1~3

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6. Conclusions

The paper introduces a vibration reduction design method of low-floor tramcar equipment., which adopts a rigid-flexible coupling dynamics model by SIMPACK, the equipment frequency is calculated. The frequency of the equipment is optimized by the calculation of the stationary and dynamic deflection. This paper provides a theoretical reduction for low floor tramcar's roof equipment.

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