The Fifth International Conference on Railway Technology
RAILWAYS 2022
22–25 August 2022
Montpellier, France

Proceedings of the Fifth International Conference on
Railway Technology:
Research, Development and Maintenance
Edited by J. Pombo
Civil-Comp Conferences, Volume 1, Paper 22.14
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.22.14

Location Distribution Effect of Under-chassis Equipment on Railway Vehicle Vibration Characteristics

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Abstract

The location of high-speed railway vehicle under-chassis equipment has a great influence on the vibration response characteristics of a car body. In order to study such effect, a rigid-flexible coupling dynamics model of the high-speed railway vehicle is established. Since the single-point response cannot represent the vibration performance of the entire vehicle body when the equipment distribution is adjusted, an upper envelope of multiple response points is proposed as an evaluation index. By analyzing the variation trend of the envelope peak value of different equipment positions, the influence law of the position distribution on the vibration response of the vehicle body is obtained, providing the distribution matching relationship of multiple under-chassis equipment for vibration reduction and vehicle comfort improvement.

Keywords: railway vehicle, under-chassis equipment, location distribution, vibration response, upper envelope, rigid-flexible coupling dynamic model.

1 Introduction

Recently, the impact of equipment arrangement is a real issue that needs to be considered in vehicle design, and equipment arrangement largely depends on engineering experience. If the matching relationship between the multiple positions under the car is unsuitable, it will increase the vibration of the body and cause the risk of resonance. Therefore, it is of great significance to study the influence of different equipment location distribution on vehicle vibration. According to the relevant research results, corresponding rules can be provided to reduce vibration and improve the ride comfort of the vehicle.

In this paper, the influence of different distribution of off-vehicle equipment on the vibration transfer characteristics of railway vehicle body is studied. First, a mathematical model of a vehicle in curb state with multiple devices is established. Using this model, the frequency response function is obtained by numerical calculation. The influence of equipment distribution on vehicle vibration characteristics is studied. In addition, the study found that a single response point does not provide a comprehensive vibration assessment criterion when studying the effects of equipment distribution. To solve this problem, a multi-point envelope evaluation method is proposed to analyze the influence of different equipment arrangements on vehicle body vibration.

2 Methods

2.1 Vehicle Rigid-Flexible Coupling Dynamics Model

As shown in Figure 1, a rigid-flexible coupling dynamic model of a railway vehicle and multiple under-chassis equipment is established. The partial differential equation of the body vibration is:

$$\begin{aligned} EI\frac{\partial^4 z(x,t)}{\partial x^4}+\mu I\frac{\partial^5 z(x,t)}{\partial t\partial x^4}+\rho\frac{\partial^2 z(x,t)}{\partial t^2} &= \sum_{i=1}^{2} k_s[z_{bi}-z(l_{bi},t)]\delta(x-l_{bi})+\sum_{i=1}^{2} c_s[\dot{z}_{bi}-\dot{z}(l_{bi},t)]\delta(x-l_{bi}) \\ &\quad +\sum_{j=1}^{n} k_{eqj}[z_{eqj}-z(l_{eqj},t)]\delta(x-l_{eqj})+\sum_{j=1}^{n} c_{eqj}[\dot{z}_{eqj}-\dot{z}(l_{eqj},t)]\delta(x-l_{eqj}) \end{aligned} \tag{1}$$

Equation (1) can be solved by utilizing Green’s function method and the superposition principle [1][2]:

$$\bar{Z}(x)=\int_{0}^{L} f(\xi)G(x,\xi)d\xi \tag{2}$$

The characteristic frequency of the vehicle body can be determined by equaiton (2). Combined with the known suspension frequency, the relationship function between vehicle body vibration and equipment position can be derived.

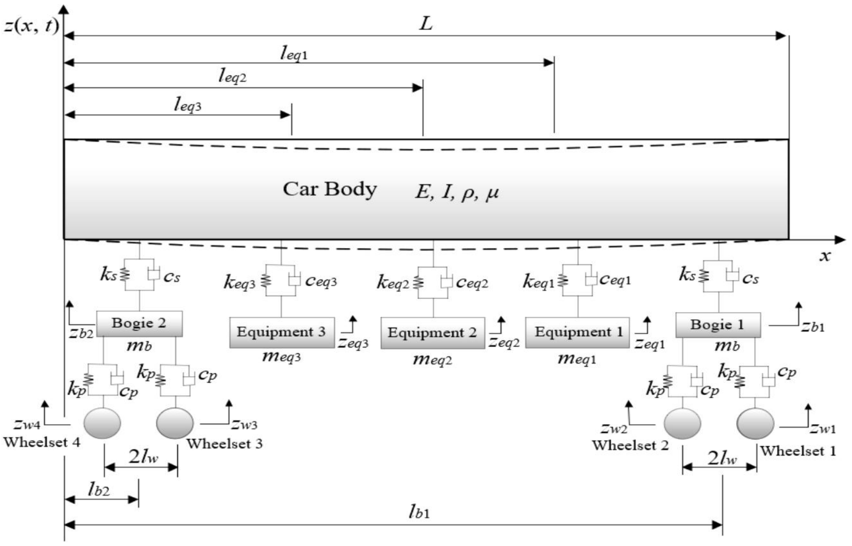

Figure 1: Model of the railway vehicle

2.2 Multi-point Evaluation Method of Vehicle Response

It is found that when the position distribution is asymmetric, the first-order vertical bending mode shape of the vehicle body may no longer be centrosymmetric.[3] It makes it difficult to understand how body responds changes. Furthermore, when the position of the equipment changes, it's impossible to find a specific point that represents the vibration of the body.

This paper proposes a method to jointly evaluate vehicle body vibration using the upper envelope of multiple response points.The frequency response curves of all response points are shown in Figure 2, and the red bold dotted line represents the upper envelope of these response curves. The upper envelope consists of the maximum response value among all response points corresponding to each frequency.This upper envelope curve can characterize the change in the body's highest response in each frequency band when changing any parameter of the equipment.

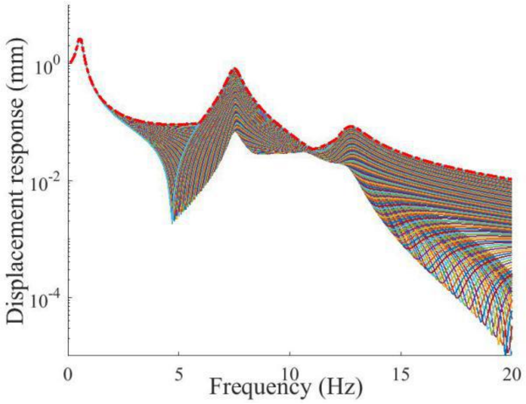

Figure 2: Response curves and their upper envelope

3 Results

In the case of elastic suspension of all equipment, equipment 1 and 3 are moved to both sides with a step of 1m to study the change of the displacement frequency response envelope curve of different positional arrangement combinations.

The symmetrical distribution of the devices is shown in Figure 3, showing the change in the displacement frequency response envelope when devices 1 and 3 move synchronously and equidistantly in the direction away from the center of the chassis. It can be seen that as the components of the devices on both sides move away from the center, the first peak gradually decreases, while a new peak appears almost behind it. The new peak gradually becomes more obvious, but is always lower than the first peak. At the same time, the second peak gradually increases as the device moves.

Figure 4 and 5 show the variation of the envelope curve with the position of device 1 when the positions of device 3 are 6m and 8m, to determine the effect of asymmetric distribution of devices. It can be found that, regardless of the asymmetry, as long as there is one device far from the center of the chassis, there is a pattern of the first peak falling and the second peak rising. Also, the more asymmetrical the two devices, the larger the gap between the first peak and the new peak. A change in the device's location produces a corresponding change. As a result, this causes the response of various points in the body to change.

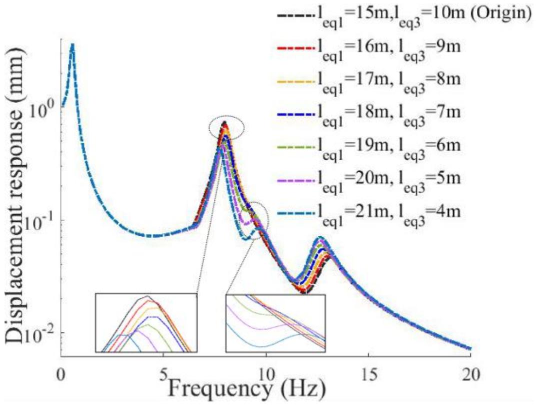

Figure 3: Symmetrically distribution

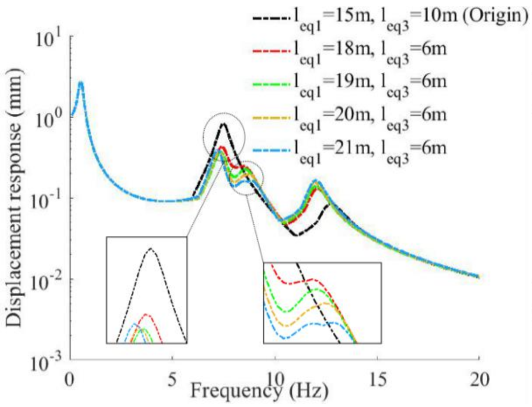

Figure 4: Equipment 3 at 6m

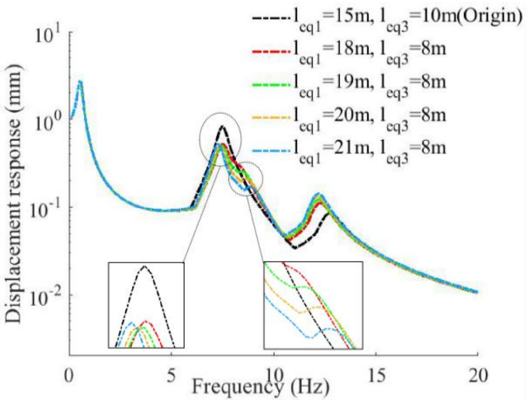

Figure 5: Equipment 3 at 8m

Figure 6 and 7 illustrate the variation of the first and second peaks in the envelope curves for all possible combinations at different positions. The peak range of the envelope curve for different combinations of device positions can be estimated from Figure 9. It can also be seen that the first peak in the envelope curve decreases as the two pieces of equipment move away from the center of the vehicle, while the second peak increases as the equipment moves. In order to compromise, when designing the location of the equipment arrangement, it is necessary to consider that the equipment on both sides cannot be too far from the center or too close to the center.

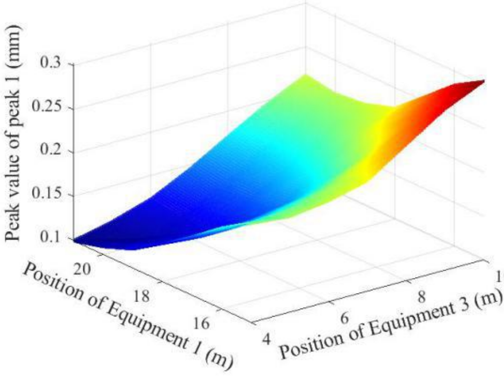

Figure 6: Variation of The first peak

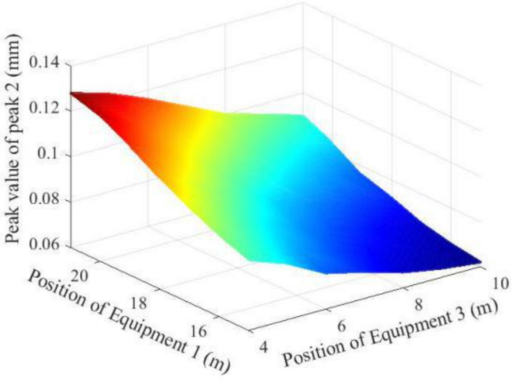

Figure 7: Variation of The second peak

4 Conclusions and Contributions

The results show that when studying the influence of equipment distribution changes on the vibration response characteristics of the vehicle, the commonly used method of selecting a single response point to view the response cannot represent the vibration changes of the entire vehicle body. To this end, a method for calculating the envelope over multiple response points considering the vibration response of the entire vehicle body is proposed.

The theoretical and simulation research results show that regardless of the symmetry, as the device moves away from the center, the first peak gradually decreases and the second new peak gradually becomes higher. However, it is always lower than the first peak. The range of the envelope peaks for different combinations of device positions is estimated. The first peak in the envelope decreases as the two pieces of equipment move away from the center of the vehicle, while the second peak increases as the equipment moves. For a single device, the closer to the center of the vehicle the better. For multiple devices, it's necessary to consider that the devices on both sides cannot be too far from the center or too close to the center when designing the location of the equipment.

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