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Influence of Parameters of Hollow Worn Tread on Vehicle Stability of EMU

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Abstract

In order to investigate the influence of the hollow worn tread on vehicle stability during the operation of a certain type of high-speed EMU, a rigid-flexible coupling vehicle dynamic model considering the hollow worn tread is established, in which the elasticity of the frame and the carbody is considered. The hollow worn width, hollow worn depth and hollow worn position are proposed as parameters to define the hollow worn of tread, and the distribution curve of tread wear is accurately fitted according to these three parameters. The influence of the hollow worn parameters on the equivalent conicity, the critical speed and the lateral vibration acceleration of the frame and stability is investigated through simulation analysis. The results show that hollow worn width and hollow worn depth have a greater influence on the equivalent conicity, and that the equivalent conicity will gradually stabilise with the development of hollow worn. The influence of hollow worn depth on vehicle stability is greater than the other two parameters, and the influence is opposite before and after the inflection point (hollow worn depth is 1mm). The greater the width of the hollow worn, the better the stability of the vehicle, which demonstrates that lateral uniform wear on the tread can improves stability. This study can provide an empirical reference for the estimation of the equivalent conicity and the assessment of vehicle stability under hollow worn tread condition.

Keywords: EMU trains, hollow worn tread, stability, equivalent conicity, critical speed.

1 Introduction

According to a survey of the high-speed electric multiple units (EMU) operating on new high-speed railways in China, tread wear is mainly hollow worn. The creation and development of hollow worn progressively deteriorates the wheel-rail contact relationship, causing the wheel-rail contact points are scattered on both sides of the concave wear, as shown in Figure 1. And when the contact point jumps between the two sides, it is very easy to cause a huge impact between the wheels and rails, which can seriously lead to lateral instability of the frame and threaten the safety of vehicle operation. Alizadeh et al. [1] investigated the effect of the wheel surface hollowing on the inconstancy and vibrations of a wagon, and concluded that worn wheels should be inspected regularly and re-profiled before their false flanges exceed a limit of 2 mm, in order to prevent the hunting phenomenon, and ensure being away from derailment of a passenger railway vehicle. Jin et al. [2] carried out the detailed analysis and summary of the transverse wear of high-speed wheel/rail of China, including its characteristics, the formation mechanism, its effect on high-speed train dynamic behaviour and the measures against such wear pattern. In order to obtain the law of the influence of the development of hollow worn tread on the operational stability, this paper firstly proposes the parameters that can accurately fit the distribution of hollow worn, and establishes a dynamical model similar to the real vehicle, and then studies the influence of changes in hollow worn parameters on the equivalent conicity of the tread, the critical speed and the lateral vibration acceleration of the frame.

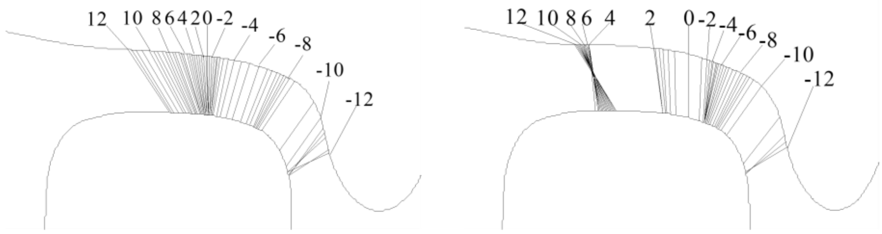

Figure 1: Wheel-rail contact relationship: (a) the newly turned wheel; (b) the wheel running for 120,000 km after turning.

2 Methods

The object of this study is a certain type of high-speed EMU. According to the dynamic parameters of the vehicle, the rigid-flexible coupling vehicle dynamic model is established, as shown in Figure 2. The model treats the carbody and frame as elastomers, and these elastomers are established by joint use of the finite element analysis software HYPERMESH and the multi-body dynamics simulation software SIMPACK[3]. The model also takes into account the non-linear parametric characteristics of the suspension elements as well as the real track irregularities. Figure 3 shows the tread profile of the newly turned wheel and the wheel running for 120,000 km after turning. As the measured hollow worn of the tread is mainly concentrated near the nominal rolling circle, this study proposes to define the hollow worn of tread in terms of three parameters: hollow worn width, hollow worn depth and hollow worn position, and the distribution curve of the wear can be fitted with a quadratic function based on these three parameters of hollow worn, see equation (1).

In the equation, x: X axis of tread, f(x): depth of wear, w: hollow worn width, d: hollow worn depth, p: hollow worn position.

Next, based on the vehicle dynamics model, the vehicle is set to run at 160 km/h. Table 1 defines the values of the hollow worn parameters at seven levels of variation. Simulations are carried out to calculate the influence of different hollow worn parameters on the equivalent conicity of the tread and stability, where stability includes the critical speed and the lateral vibration acceleration of the frame.

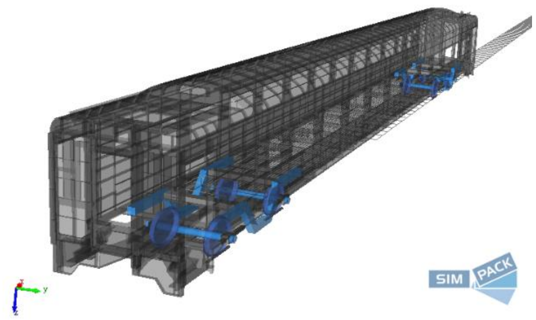

Figure 2: Rigid-flexible coupling vehicle dynamic model.

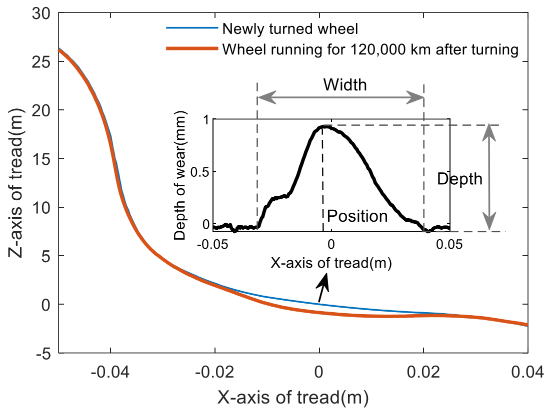

Figure 3: Hollow worn of wheel.

$$f(x)=\begin{cases}-\dfrac{4d}{w^2}(x^2-2px+p^2)+d & p-0.5w\le x\le p+0.5w \\ 0 & x<p-0.5w,\ \ x>p+0.5w\end{cases} \tag{1}$$

Level	1	2	3	4	5	6	7
Hollow worn width(mm)	35	42	49	56	63	70	77
Hollow worn depth(mm)	0.25	0.5	0.75	1	1.25	1.5	1.75
Hollow worn position(mm)	-3	-2.5	-2	-1.5	-1	-0.5	0

Table 1: Values for different levels of the hollow worn parameters.

3 Results

Figure 4 shows the influence of parameters of hollow worn on the equivalent conicity of the tread. The equivalent conicity tends to decrease and then stabilise as the hollow worn width increase, and when the hollow worn width is increased to 49 mm, the rate of decrease of the equivalent conicity becomes significantly smaller and gradually stabilises. The equivalent conicity of the tread decreases by 43% when the hollow worn width is increased from 35mm to 49mm. The equivalent conicity tends to increase and then stabilise as the hollow worn depth increase, and when the hollow worn depth exceeds 1mm, the equivalent conicity reaches a steady state. When the equivalent conicity varies with the hollow worn position, the equivalent conicity is greatest in the range of -1 to -0.5mm, and decreases the further away from this range.

Figures 5 and 6 show the influence of parameters of hollow worn on the lateral vibration acceleration of the frame and the critical speed respectively. It can be seen from the results that the lateral vibration acceleration of the frame tends to decrease as the hollow worn width increases, and the decreasing trend is more obvious when the hollow worn width increases from 70mm to 77mm. The critical speed tends to rise and then fall with the increase of the hollow worn width, but the subsequent fall is not extensive. With the increase of the hollow worn depth, the lateral vibration acceleration of the frame tends to increase and then decrease, and the critical speed tends to fall and then rise, and the inflection point of both indicators is at the hollow worn depth of 1mm. With the left shift of the hollow worn position, the lateral vibration acceleration of the frame has no obvious trend change, but the critical speed tends to rise, and when the left shift of the hollow worn position to -1mm, the critical speed reaches a stable value.

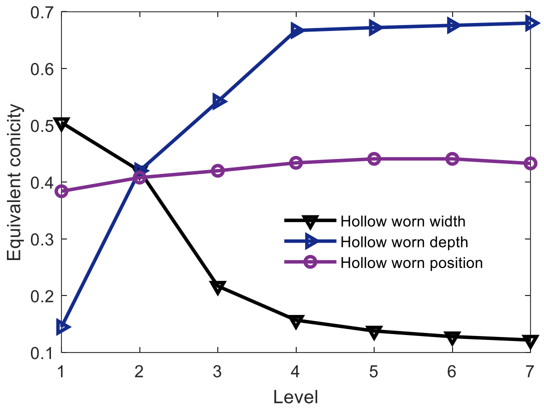

Figure 4: Influence of the parameters of hollow worn on the equivalent conicity.

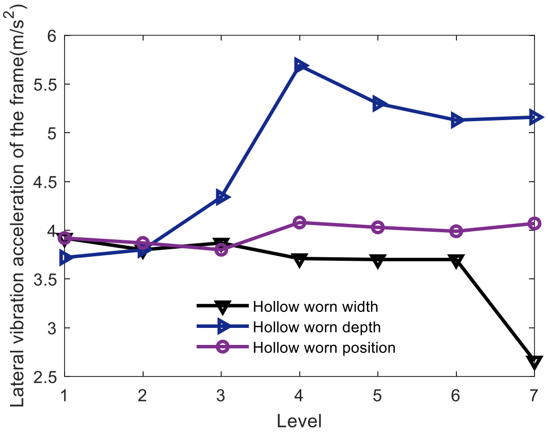

Figure 5: Influence of the parameters of hollow worn on the lateral vibration acceleration of the frame.

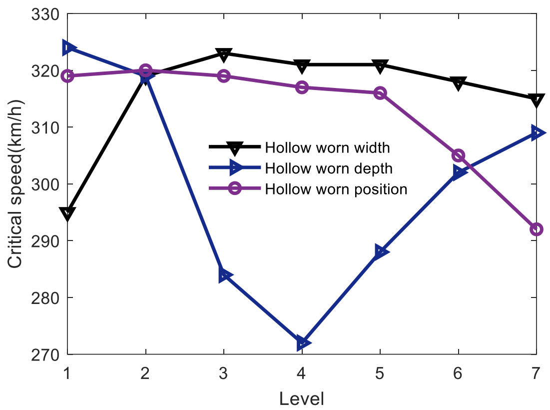

Figure 6: Influence of the parameters of hollow worn on the critical speed.

4 Conclusions and Contributions

This study proposes the use of hollow worn width, hollow worn depth and hollow worn position as parameters to define hollow worn of the tread, and the distribution curve of the wear can be fitted based on the three parameters. Based on the analysis of the simulation results, it is found that the hollow worn width and the hollow worn depth have a greater influence on the equivalent conicity of the tread, but the equivalent conicity will both gradually stabilise with the development of hollow worn. The influence on the equivalent conicity is not significant when the hollow worn position varies from 0 to -3 mm. By extending this influence law, it is possible to estimate the equivalent conicity of the tread based on the values of three dimensions: hollow worn width, depth and position. The influence of the hollow worn depth on vehicle stability is greater than the other two parameters, and the inflection point is at 1mm, i.e. the influence law of the hollow worn depth on vehicle stability is reversed before and after the inflection point. The greater the hollow worn width, the greater the vehicle stability, which also demonstrates the importance of lateral uniform wear on the tread, avoiding concentrated wear in one location and thus reducing the problem of rapid loss of stability. This study can provide an empirical reference for the assessment of the vehicle stability of hollow worn tread conditions.

Acknowledgements

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