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Evaluation Methods of Carbody Hunting Instability of Railway Vehicles

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Abstract. In order to analyze and make the criterion of carbody primary hunting instability, the relationship among equivalent conicity, vehicle speed and hunting frequency has been analyzed firstly. To simulate different vehicles' carbody hunting instability, this article analyzed the lateral acceleration signals of a simulated full-scale vehicle under several conditions. Through these data, an amendatory method for calculating centroid frequency of vehicle lateral vibration is presented and an index named power concentration ratio (PCR) is presented for distinguishing carbody primary hunting and the data with larger amplitude is screened under the ride index. According to the statistical law, the criterion of carbody primary hunting instability is summarized. Research result shows that the there is a vehicle carbody hunting instability while the lateral acceleration with filtered 0.5–3 Hz exceeds 0.5 m/s^2 for six times serially in 15 s. The criterion is shown to be valid through the field test data.

Keywords: Carbody hunting instability · Evaluation method · Centroid frequency · Power concentration ratio · Ride index

1 Introduction

Hunting instability motion is an inherent character of the railway vehicle while running on the rail. Considering that it can directly affect the vehicle's critical evaluation parameters such as the critical speed and Sperling index, the vehicle lateral dynamics performance derived from it has always been one of the research focuses of railway researchers [1, 2]. Vehicle hunting instability motion can be divided into two forms: carbody hunting instability (primary hunting instability) and bogie hunting (secondary hunting instability) [3]. Bogie hunting instability without effective damped measure can not only aggravate the wear between the wheel and railway, but also deteriorate the vehicle dynamics performance [4, 5]. A series of standards show indexes or clauses to distinguish the bogie hunting instability, while few standards and researches have been set up for carbody hunting instability. [6] considers the amplitude of carbody displacement as an evaluation index to estimate carbody hunting instability. Carbody hunting is screened out combining the vibration frequency and ride index in [7]. The vehicle ride index can noteworthily increase due to carbody hunting instability, so

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identifying carbody hunting instability fast and accurately could warn the operators to take steps to avoid potential risks, which is significant for updated vehicles with active control suspension system. Because ride index is derived from weighted computation, several carbody hunting signals may be ignored. In addition, high-frequency vibration, which is obviously not the carbody hunting instability, can also lead to the growth of the index. This article analyzes carbody lateral vibration acceleration of different vehicle simulation models, and summaries the carbody hunting instability criterion. Through the statistical data from the perspectives of frequency domain and power concentration ratio (PCR), the criterion considers the acceleration peak and the number of time that the signal exceeds a threshold continuously.

2 Modeling and Identification of Carbody Hunting Conditions

The vehicle model, based on a carbody hunting vehicle, is built by SIMPACK, and the model is based on a vehicle which once hunted during its line operation condition. The signals, seen in Fig. 1, between simulation model and operation vehicle are both similar under time and frequency domains, which proves that the model is built correctly.

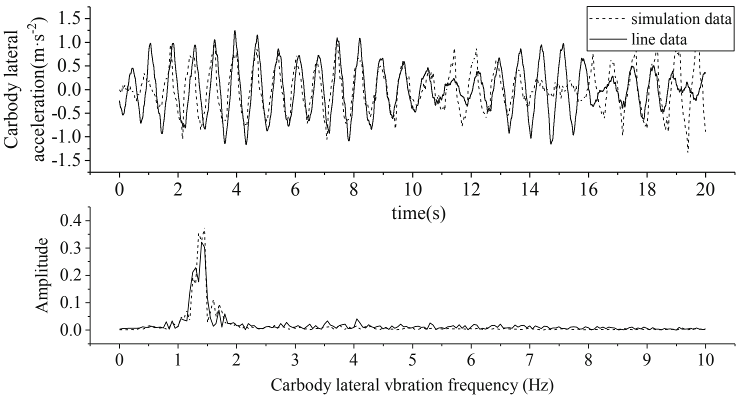

Fig. 1. The data of simulation and line condition

For simulating various railway vehicle types and operating conditions, a series of parameters are adjusted, including various rail excitations, rail surfaces, tread profiles, suspension parameters, speed, etc. The carbody vibration signal is filtered by 0.5–10 Hz.

The relationship among vehicle speed, equivalent conicity, and frequency of vehicle hunting (generally known as bogie hunting), is analyzed, as seen in Fig. 2. The frequency increases with the rise of vehicle speed and equivalent conicity respectively, and with the speed raising, the lower the equivalent conicity, the lower the growth rate of frequency. The mechanism of carbody hunting instability (carbody visible waggle), which is generally accepted, is that the frequency of vehicle hunting close to the vehicle yaw and roll natural frequency (generally lower 3 Hz), especially when the damping ratio is insufficient. So, the low frequency of vehicle hunting, which corresponds to the equivalent conicity in Fig. 2, can explain the reason why the carbody hunting instability can be measured when the vehicle is under a high speed in a field test, which is uncommon.

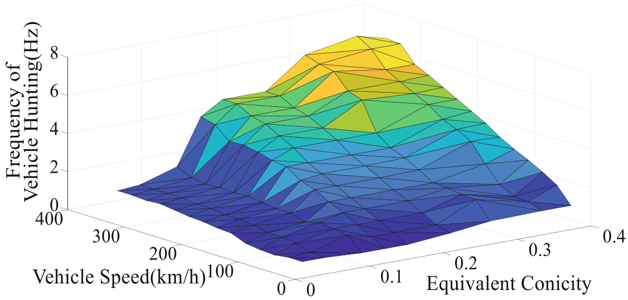

Fig. 2. The relationship figure among vehicle speed, equivalent conicity and frequency of vehicle hunting

3 Identification of Carbody Hunting Main Frequency

When there is a carbody hunting, the dynamic characteristic of carbody lateral vibration can be approximately described as a narrow-band random process and the carbody hunting frequency can be calculated as the centroid frequency [8].

3.1 Centroid Frequency

Spectral moment is a method of describing spectral density. When the mean value of the stationary stochastic process X(t) is 0, the k-order spectral moment of the stationary stochastic process can be used to define the centroid frequency. It can be described by its single-sided spectral density $G_x(\omega)$, as shown in the following equation,

$$\lambda_k = \int_0^\infty \omega^k G_X(\omega)\mathrm{d}\omega, \quad (k = 0, 1, 2, \ldots) \tag{1}$$

And the corresponding parameters can be expressed as

$$\omega_k = \left(\frac{\lambda_k}{\lambda_0}\right)^{\frac{1}{k}}, \quad (k = 0, 1, 2, \ldots) \tag{2}$$

When k = 1, ω_1 is the centroid frequency of area surrounded by the curve.

3.2 Frequency Correction

Since the frequency of carbody hunting is normally much less than the upper limit of filtered frequency [7, 9], the calculated centroid frequency is higher than the actual frequency. The corrected algorithm uses the original calculated centroid frequency as the filter median frequency instead of 10 Hz and calculates the corrected centroid frequency again. The spectrum amplitude with LOWESS can be summarized to 2 situations: the first one is when the highest peak of the spectrum is the first peak (I), while the other conditions belong to the second situation (II). The correction algorithm is available for situation I (see in Fig. 3), nevertheless is invalid for the II.

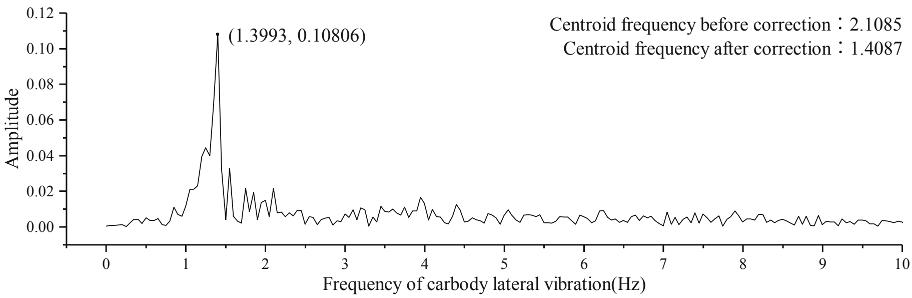

Fig. 3. Comparison of the centroid frequency with and without correction (situation I)

3.3 Power Concentration Ratio

Since carbody hunting signal satisfies the characteristic of a classical narrow-band random process, so in order to distinguish the carbody hunting conditions, an index named power concentration ratio (PCR) is presented in this article. PCR, ratio of power content in a special frequency region, means the degree of power concentration near a special frequency in the power spectral density analysis, which emphasizes the certain area near the centroid frequency in this article.

$$PCR = \int_{f\mathrm{down}}^{f\mathrm{up}} P(f)dt / \int_{0}^{+\infty} P(f)dt, \quad (k = 0, 1, 2, \ldots) \tag{3}$$

Based on the analysis of the time domain signals, it is feasible that the PCR is 85% for 0.4 Hz above and below the centroid frequency, 80% for 0.3 Hz, and 70% for 0.2 Hz. If a signal can satisfy three conditions above, it can be judged as a carbody hunting (see Fig. 4). 74.4% of all the ride index over 2.5 and all the ride index over 2.75 are carbody hunting conditions, and the centroid frequencies of all screened conditions are under 2.3 Hz, which are consistent with the normal characteristics of carbody hunting.

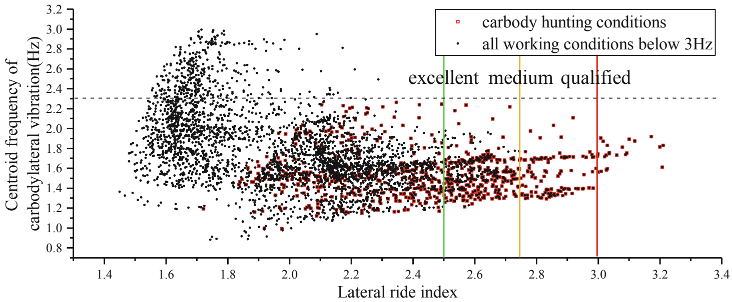

Fig. 4. The comparison of lateral ride index of carbody hunting and all conditions

4 Analysis of Judgement Criterion

In all carbody hunting conditions, the amplitude of lateral acceleration in several conditions is too small to get an accurate criterion, which could lead the statistical result lower than the authentic one, so it is necessary to get rid of the low amplitude conditions. These conditions that the lateral ride index below 2.5 are not considered in the analysis of the carbody hunting instability criterion.

According to the data of candidate conditions, the ratio of conditions that amplitude continuously exceeds specified thresholds to all conditions can be seen in Fig. 5. With the decreasing of continuous time and acceleration limit respectively, the ratio has an upward trend. The ratio is 81.25% for the conditions that the carbody lateral acceleration peak over 0.5 m/s^2 for 6 times continuously, while there is an obvious decline with the increase of continuous time and acceleration peak respectively. Considering the overall data, it is feasible to use the 0.5 m/s^2 as the limit peak value, and the continuous time as 6.

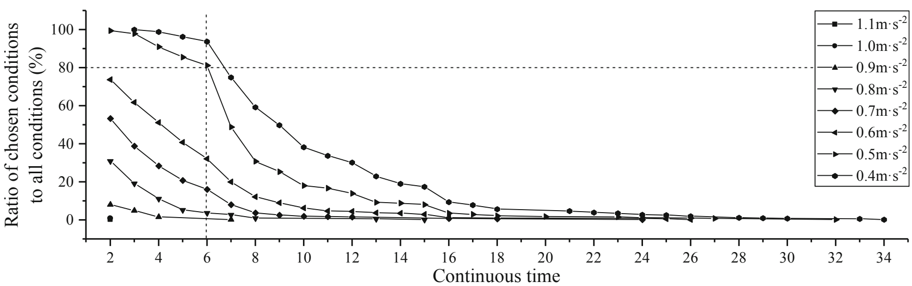

Fig. 5. Ratio of conditions that continuously exceed specified thresholds to all conditions

Through the verification of field test data with or without obvious carbody hunting instability in Fig. 6, the criterion is advisable for judging the carbody hunting instability.

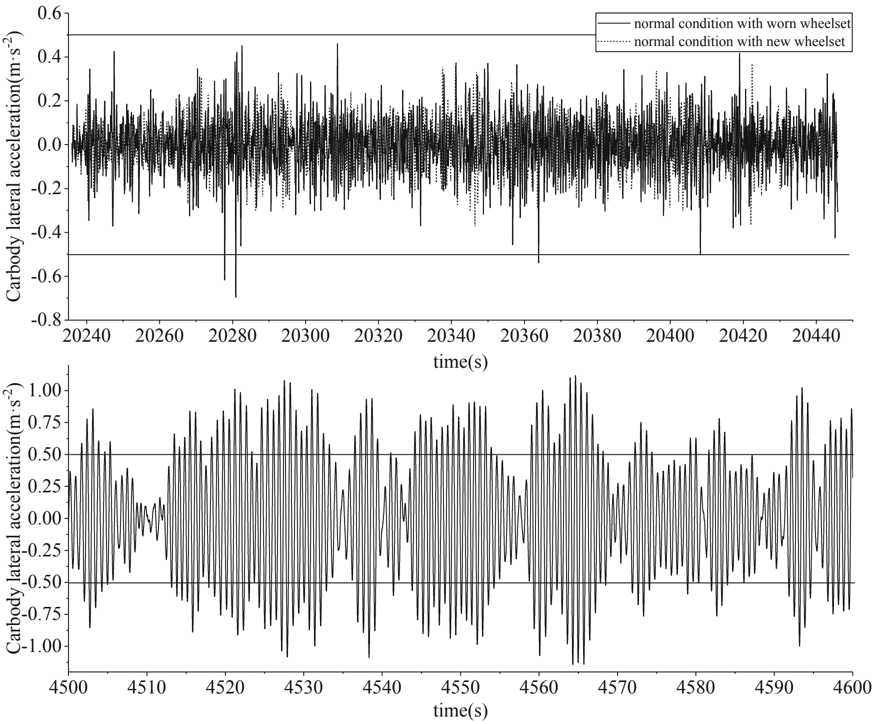

Fig. 6. Carbody lateral acceleration under normal condition (above) and hunting condition (down)

5 Conclusion

In conclusion, the criterion of the carbody hunting instability is: the lateral acceleration of measurement points with filtering 0.5–3 Hz exceeds 0.5 m/s^2 for six continuous times in 15 s, and the test points are placed on the inner floor from 1000 mm to the carbody center line and over the front and rear bogies respectively.

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