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Time-frequency analysis of wheel-rail shock in the presence of wheel flat

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Abstract: Against the deficiencies of traditional time domain and frequency domain analysis in detecting wheel-rail (W-R) system hidden risks which wheel flats generate, the time-frequency characteristics of W-R shock caused by wheel flat are analyzed and the vehicle-rail dynamic model with wheel flat is investigated. The 10 degrees of freedom (DOF) vehicle model is built up. 90-DOF rail model is constructed. The wheel flat excitation model is built up. The vehicle-track coupling dynamic model including wheel flat excitation is set up through nonlinear Hertzian contact theory. The vertical accelerations of axle box are calculated at different speeds and flat sizes based on the vehicle-track coupling dynamic model with wheel flat. Frequency slice wavelet transform (FSWT) is employed to analyze time-frequency characteristics of axle box accelerations to detect the W-R noncontact risks, which the traditional time domain or frequency domain method does not analyze. The results show that the small flat size and high running speed lead to high frequency W-R impact. Large flat size and high running speed result in momentary loss of W-R contact, and there exist security risks between wheel and rail. The conclusion that the phase of axle box accelerations is same to W-R forces lays a theoretical foundation of monitoring W-R contact safety from axle box acceleration instead of traditional W-R force detection.

Key words: railway vehicle; wheel flat; wheel-rail shock; frequency slice wavelet transform; time-frequency characteristic

1 Introduction

It is unavoidable that wheel flats appear due to wheel lock and sliding along the rail when railway vehicle brakes or runs in low friction conditions. The wheel flats circularly shock W-R system and induce large periodic W-R shock forces when wheel rotates at high speed. Statistically, the dynamic wheel-rail (W-R) impact forces caused by wheel flat are several times larger than static W-R forces (Bray et al. 1973; Dukkipati and Dong 1999; Jergéus et al. 1999; Belotti et al. 2006; Baeza et al. 2006a, 2006b; Uzzal et al. 2009; Brizuela et al. 2010, 2011; Zhao et al. 2012; Ding et al. 2013; Ding et al. 2014). As a result,

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high cycle fatigue, crack appearance, crack fast propagation of the key components, such as rails, sleepers, wheels, bearings, will seriously affect and reduce vehicle and track service lives and endanger vehicle operation safety. At the same time, a periodic impact noise is produced in addition to the usual rolling noise, which is more random and non-stationary in character due to wheel flat shock (Newton and Clark 1979; Fermer and Nielsen 1994; Johansson and Nielsen 2003; Stratman et al. 2007). Therefore, it is necessary and urgent to analyze W-R system shock characteristics caused by wheel flats and study its corresponding detection methods which have great significance on vehicle maintenance and safe operation.

Domestic and foreign scholars have made a lot of research work and achieved fruitful results in the vibration characteristics analysis of the wheel flats. Researchers established vehicle-track coupling dynamic model to analyze dynamic responses at different operation speeds and different flat sizes and drew three very important conclusions through the time domain or frequency domain analysis (Bracciali and Cascini 1997; Zhai et al. 2001; Wu and Thompson 2002; Madejski 2006; Ding et al. 2013). The first is that W-R force increases with the increase of flat size. The second is that the W-R force firstly increases then decreases with the increase of operation speed. Finally, peak frequency distribution of W-R force is analyzed. These conclusions provide a scientific basis for wheel removal, reasonable running speed control and optimization design of vehicle track system. But in time or frequency domain, the classical analysis methods do not analyze the W-R contact characteristics under the course of W-R dynamic interaction.

In this paper, the time-frequency analysis using the frequency slice wavelet transform (FSWT) is employed to extract the character of losing contact between wheel and rail. The vehicle-track coupling dynamic model is set up in the second section. The dynamic response is solved under different running speeds and flat sizes in the third section. In the fourth section, the FSWT is employed to analyze the time-frequency characteristics of the axle box vibration acceleration caused by wheel flats and to detect the hidden risks of W-R contact loss. Finally, the conclusions are drawn.

2 Vehicle-track coupling dynamic model simulating wheel flat

Dynamics simulation mechanism of wheel flat is shown in Fig. 1. It mainly includes 10 degrees of freedom (DOF) vehicle dynamic model, 90-DOF track dynamic model and wheel flat excitation model. The vehicle-track coupling dynamic model including wheel flat excitation is built up through nonlinear Hertzian contact theory. The W-R normal compression amount is calculated through the displacement of wheel, rail and track irregularity including the wheel flat effect. The W-R forces are obtained by applying the W-R normal compression amount and nonlinear Hertzian contact theory and are regarded as feedback of vehicle model and track model to execute the dynamic simulation.

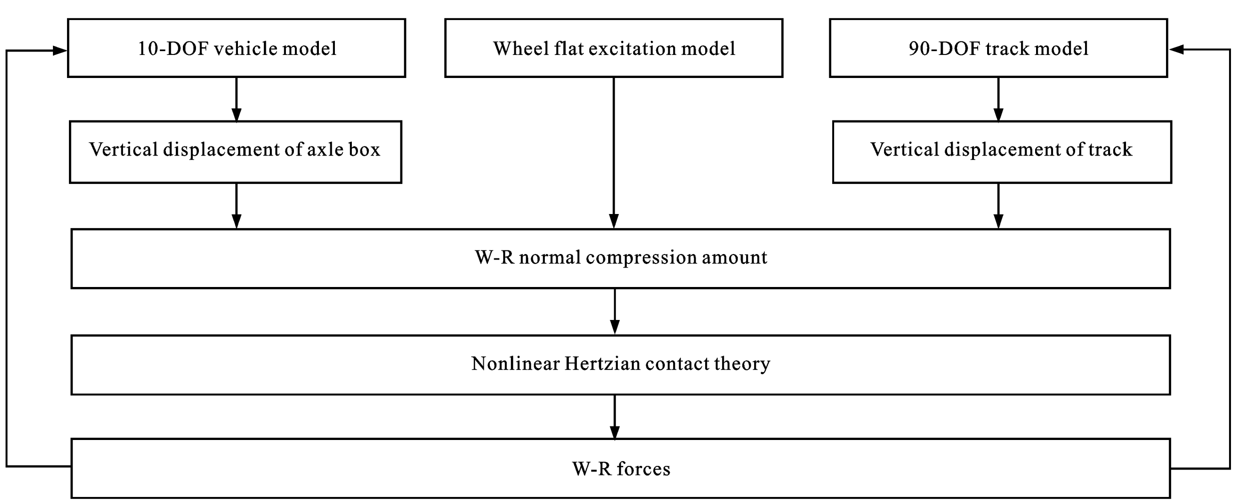

Fig. 1 Dynamics simulation mechanism of wheel flat