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Relation Between Track Irregularity of Speed-Increased Railway and Dynamic Speed Limits Through Simulation

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Abstract: Based on the vehicle-track coupled dynamics theory and the corresponding simulation software ADAMS/Rail software package, a vehicle-track coupling system model is established, and the track irregularity is introduced to the coupling system model as an excitation source. Firstly, the dynamic responses of speed-increased railway vehicle and track components due to different types of track irregularity are obtained. Secondly, the sensitive wavelength of different track irregularities in high-speed operation is discussed. Finally, suggestions about the maximum operation speed to meet the standards value of daily maintenance target, comfortable value, emergency repair and speed management target are put forward.

Keywords: Dynamic speed limits, speed-increased railway, track irregularity, vehicle-track coupled model.

1. INTRODUCTION

As the speed of the trains continues to increase it poses a threat to the integrity of the track whose condition has an integral effect on train operation safety and ride comfort. The vibration of the vehicle and track components, due to track irregularities, increases as the train’s speed increases. The wavelength ranges of track irregularities corresponding to the larger responses of vehicle system also vary with vehicle running speed. The low-frequency lateral vibration of car body is more obvious, and track irregularity is one of main factors that directly limit the speed and quality of train operation in -increased-speed and high speed railway.

A large number of studies on track irregularity management and control standards have been done by both the researchers in China and worldwide [1-6]. In developed countries such as France, Japan andGermany a series of track irregularity management standards and control measures are developed, combined with the characteristics of domestic railway transport and track structure. Such as track operation acceptance standards, daily maintenance standards, emergency repair standards, speed management standard, Japan's P value, 300 meters moving average quality index of France, track section standard deviation of Germany and Britain, and so on. These standards provide technical support for ensuring operation safety and ride comfort of train as well as the development of high-speed railway.

The development of high-speed railway in China is later than developed countries. As gross passing tonnage and vehicle running quality are different in different countries, the foreign high-speed track irregularity management standards and control measures are not applicable in China. In order to reduce costs for maintenance of track infrastructure and to increase railway productivity, it is important to study the relation between track irregularities of speed-increased railway line and dynamic operation speed limits.

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2. SIMULATION MODEL

By means of the vehicle-track coupled dynamics theory [7] and the corresponding simulation software Adams' multi-body software package, a vehicle-track coupled system model that consists of the vehicle sub-model and the track sub-model is developed.

In the vehicle sub-model (Fig. **1**) the model comprises of 7 bodies with 42 degrees of freedom. A rigid car body, two two-piece bogies, and four wheel sets. The car body is supported on two two-piece bogies at each end, The bolster less bogies are linked with the car body by the secondary suspensions and linked with the whee1sets by the primary suspensions. The primary and secondary suspensions are represented through spring-damper elements. The vehicle is assumed to move along the track at a steady-state velocity, Wheel tread uses the high-speed wheel profile LMA. Air spring is represented by Krettek air spring. The spring-damper elements are nonlinear.

In the track sub-model, the ballasted track is considered which comprises of the rails, the pads, the fasteners, the sleepers, the ballast, and the subgrade arranged in four layers. Both the left and right rails are treated as continuous Bernoulli-Euler beams which are discretely supported at fastener junctions. The sleepers are considered to be rigid, and linked with the rails and the ballast through spring-damper elements, The vertical, horizontal and torsional vibrations of the rail are taken into consideration. The vehicle subsystem is coupled with the track subsystem by the whee1 rail coupling model at the wheel-rail interfaces, The

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wheel rail dynamic forces are calculated according to Hertz nonlinear elastic contact theory in this paper,

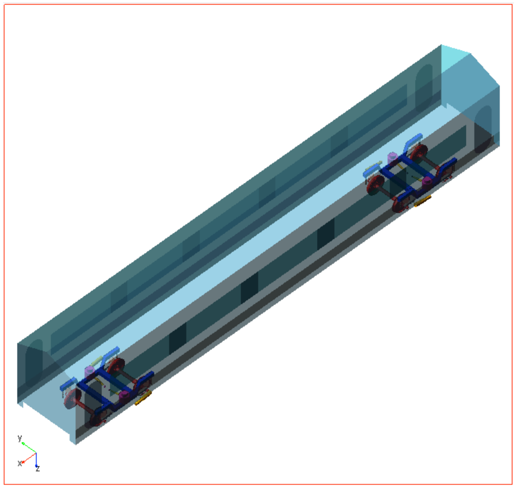


Fig. (1). The vehicle sub-model in ADAMS.

The track irregularity refers to the deviation of the rail actual geometry from its ideal geometry. It is introduced to the coupling system model as the excitation source. These irregularities are characterized by the lateral and vertical displacement of each rail, which are generally known as vertical profile, alignment, gauge, and cross-level. In this study, the lateral and vertical rail disturbances are considered as pure cosine wave functions to simulate the track irregularity. The mathematical model is defined by the following equation

$$Z_0(t) = \frac{1}{2}a\left(1-\cos\left(\frac{2\pi v}{L}t\right)\right) \qquad 0 \le t \le \frac{L}{v} \tag{1}$$

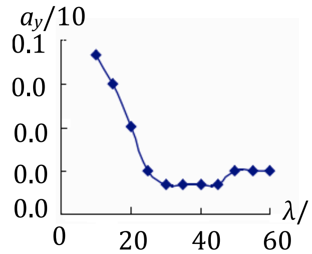
where, L is the wavelength of track irregularity, a is the amplitude of rack irregularity, v is vehicle velocity, and t is time.

Simulations were performed in Adams/Rail software package. In this paper, track rail vertical profile irregularity is chosen as an example. Space lacks for a detailed description of other simulation results including track rail cross-level, alignment and gauge irregularities.

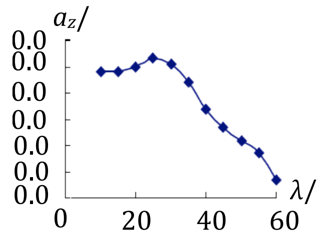
3. SENSITIVE WAVELENGTH OF TRACK IRREGULARITY

By use of the train-track coupled model, taking CRH2 EMU high speed rail train and speed-increased railway ballasted track as an example, the dynamic responses of vehicle under the various track conditions and operation velocities are analyzed through numerical analysis. Vertical and lateral wheel/rail forces, wheel unloading rate, derailment coefficient, acceleration of the car body and comfort index are used to evaluate the vehicle dynamics performance. The amplitude value of track irregularity is 5 mm, the wavelength is within the range 10~60 m with an increment of 5 m. The vehicle is assumed to move along the track at a constant traveling velocity of 200 km/h, For the rail vertical profile irregularity, the effect of wavelength on the dynamic response of the vehicle system is shown in

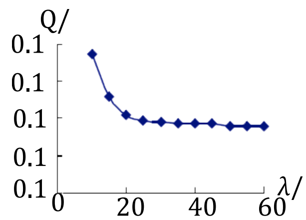
(**a**) Lateral acceleration of car body versus wavelength



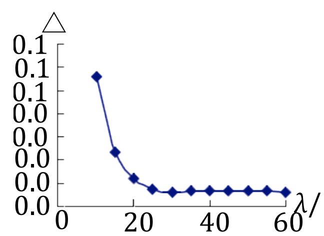
(**b**) Vertical acceleration of car body versus wavelength



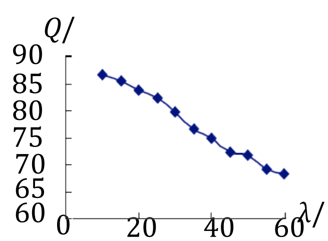
(**c**) Derailment coefficient versus wavelength



(**d**) Wheel unloading rate versus wavelength



(**e**) Horizontal wheel/rail force versus wavelength



(**f**) Comfort index versus wavelength

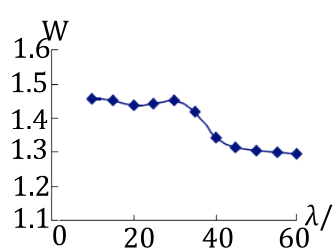


Fig. (2). Dynamic indexes versus wavelength.

Fig. (**2**). Comparing the simulation results it is observed that incident wavelength of vertical profile irregularity has little effect on lateral car body acceleration, derailment coefficient, lateral wheel/rail force and comfort index. While incident wavelength has great impact on both wheel unloading rate and vertical acceleration of the car body. It is concluded from Fig. (**2b**) that vertical acceleration of car body and wavelength are nonlinearly related. It increases when wavelength is in the range of 10~25 m and decreases in the range of 25~60 m. The vertical acceleration of car body is largest when wavelength reaches 25 m. Results according to Fig. (**2d**) indicate that wheel unloading rate decreases with incident wavelength and reaches a maximum of 0.12 when wavelength is 10 m. According to Track Irregularity Dynamic Management Standards of Speed-increased Railway, its value is within safe limits. Based on the relation between the track vertical profile irregularity and vertical acceleration of car body, the most unfavorable wavelength that brings about the vehicle vibration is 25m.

4. INFLUENCE OF TRACK RAIL IRREGULARITY ON DYNAMIC SPEED LIMITS

Railway permanent way departments often take measures to eliminate the impact of track irregularities in maintaining sky-light. Without prompt or immediate maintenance, speed limit is important for safety operation. Based on the effect of track irregularity amplitude on the dynamic response of the vehicle system with the most unfavorable wavelength, the relation between track irregularity and dynamic speed limit is analyzed. The amplitude value of track irregularity is within the range of 3~25 mm with an increment of 1 mm and the initial rate of 200 km/h. According to The Railway Line Repair Rule and The Track and Bridge Repair Rule of 200-250 km/h Speed-up Railway Line, the acceleration management standards of the car body are divided into four levels (see in Table **1**), e.g., Daily Maintenance Standard, Comfortable Standard, Emergency Repair Standard and Speed Management Standard.

Relation between the vertical acceleration of the car body and the amplitude of track rail vertical profile irregularity is shown in Fig. (**3**). It is concluded that the largest amplitude value could be controlled within 8 mm, 12 mm, 16 mm and 20mm. When the vertical acceleration of the car body can meet the daily maintenance value of 0.10 g the irregular comfortable value of 0.15 g the emergency repair target value of 0.20 g and the speed management target value of 0.25 g respectively. It is necessary to limit train speed for safety operation, if the amplitude is above limits. The relation between speed limit and amplitude of track rail vertical profile irregularity is shown in Fig. (**4**). It is observed that track rail vertical profile irregularities with amplitude below 20 mm have little influence on train safety operation. In order to ensure passengers' comfort, it is necessary to limit the speed of train running. However, when the amplitude is greater than 20 mm, it has great influence on safety operation, therefore the train must reduce speed. When the amplitude reaches at 25 mm, the speed limits could be controlled within 108 km/h, 97.2 km/h, 72 km/h and 57.6 km/h, when the vertical acceleration of the carbody can meet the daily maintenance value of 0.10 g. the irregular comfortable value of 0.15 g, the emergency repair target value of 0.20 g, and the speed management target value of 0.25 g, respectively.

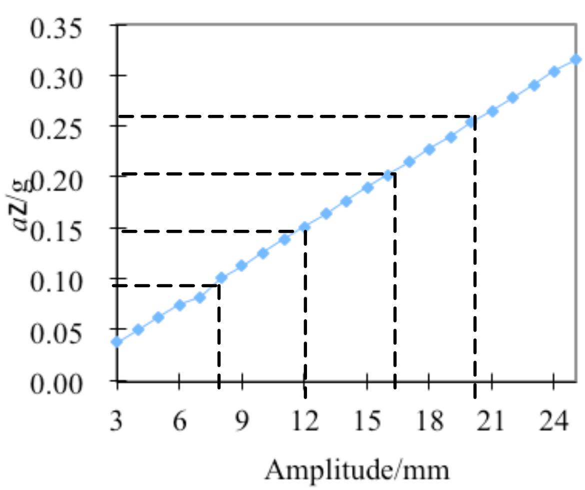


Fig. (3). Vertical acceleration of carbody versus amplitude.

CONCLUSION

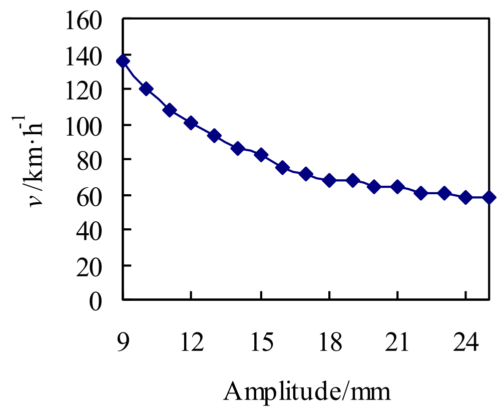
The performance of railway vehicle is dependent on the track conditions to a great extent. The loads on the vehicle induced by the track and the corresponding track forces transmitted by the vehicle operation also depend on the track geometry. It is necessary to regularly inspect and maintain the rail, to ensure the safety and reliability of high-speed railway. In process of train operation, there is a possibility that track maintenance is not timely or complete. Because maintaining sky-light is unreasonable or short. In these conditions trains must decelerate. Based on the effect of track rail irregularities on the performance of the vehicle and track dynamic systems, the dynamic vehicle speed limits were put forward when the acceleration value on the car body meets the Rail Irregularity Dynamic Management Standards of Speed-Increased Railway. The study is of theoretical significance for track maintenance. However, track rail irregularities compose of various wavelengths from

Table 1. Rail irregularity dynamic management standards of speed-increased railway.

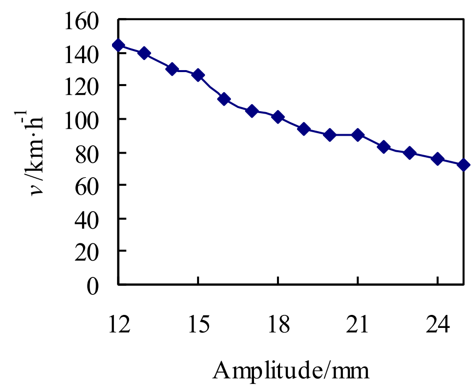
Management Standards	Vertical Acceleration of Car body/g	Lateral Acceleration of Car body/g
Daily maintenance	0.10	0.06
Comfortable standard	0.15	0.10
Emergency repair	0.20	0.15
Speed limit	0.25	0.20

several millimeters to hundreds of meters. It still needs further study for application of engineering.

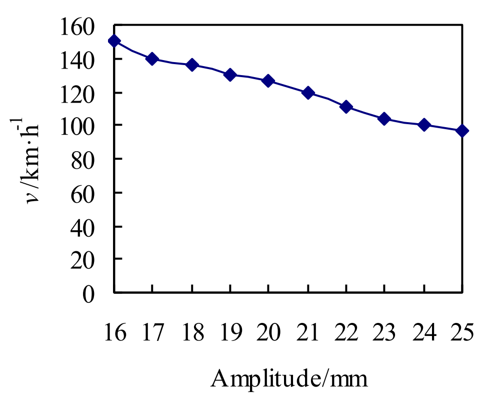
(**a**) Maximum speed to meet the standards of daily maintenance



(**b**) Maximum speed to meet the standards of irregular comfort



(**c**) Maximum speed to meet the standards of emergency repair target



(Fig. 4) contd…..

(**d**) Maximum speed to meet the standards of Speed Management target

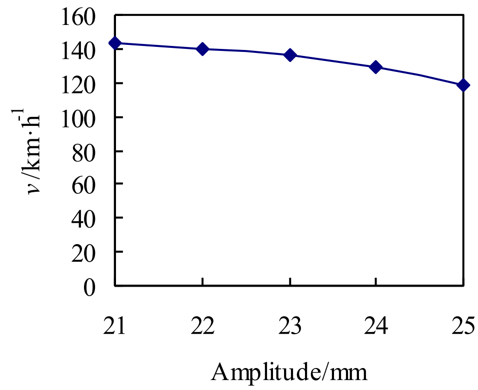


Fig. (4). Maximum speed under condition of rail vertical profile irregularity.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] K. Y. Wang and W. M. Zhai, "Effect of rail irregularity wavelength on lateral running comfort of speed-raised train", *Journal of Traffic and Transportation Engineering*, vol. 7, pp. 1-5, 2007.

[2] H. M. Shi and Z. J. Yu, "Vibration analysis of high-speed vehicles under the conditions of various speed and lines", *Journal of Beijing Jiiaotong University*, vol. 36, pp. 112-116, 2012.

[3] J. Fang and X. Y. Lei, "Research on track irregularity and unfavorable wavelength of speed-increased railway", *Journal of Railway Engineering Society*, vol. 11, pp. 27-31, 2010.

[4] J. M. Gao and W. M. Zhai, "Study on sensitive wavelengths irregularities in high-speed operation of track", *Journal of The China Railway Society*, vol. 34, pp. 83-88, 2012.

[5] João Pombo and Jorge Ambrósio, "An alternative method to include track irregularities in railway vehicle dynamic analyses", *Nonlinear Dynamics*, vol. 68, pp. 161–176, 2012.

[6] R. Iyengar and O. Jaiswal, "Random field modeling of railway track irregularities", *Journal of Transportation Engineering*, vol. 121, pp. 303-308, 1995.

[7] W. M. Zhai, Vehicle-Track Coupling Dynamics (Second Edition), Beijing: Science Press, 2001.

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