Comparison of Vehicle Dynamics Performance When Operating on High-speed Dedicated and Existing Railways

Qi Wang*

CRRC Tangshan Co., Ltd. Tangshan, China

*Corresponding Author e-mail: wangqi2@tangche.com

Abstract—In order to study the parameters difference between the high-speed dedicated and the existing railway tracks, the geometric parameters and irregularity of the two kind of tracks are compared and analyzed. The nonlinear dynamic model of Electric Multiple Units (EMU) is built, and the difference of dynamics performance of vehicle running on different railway tracks is simulated and analyzed. The results show that the track spectrum overall performance of the high-speed lines is better than that of the existing lines. At the same speed, the lateral and vertical Sperling index of vehicle running on the high-speed dedicated railway tracks is better than that of the existing railway tracks. At low speed (160km/h), when the vehicle is running on the high-speed dedicated railway tracks, the maximum and root mean square values of the frame lateral acceleration are 59.7% and 24.6% of the existing railway tracks operating conditions respectively, and the corresponding maximum and root mean square values of vertical acceleration are 49.1% and 89.8% respectively. At high speeds (350km/h), the maximum and root mean square values of lateral and vertical acceleration of the frame are 54.2%, 32.3% and 27.6%, 55.3%. With the decrease of the track curvature, the lateral wheelset force gradually increases.

1. INTRODUCTION

Track irregularity is the excitation source of wheel rail system, which directly affects the vibration of rolling stock, wheel rail interaction and the safety and comfort performance of driving. Many scholars have studied the track irregularity and the influence of track irregularity on vehicle dynamics performance[1,2]. Takai [3] divided the track irregularity into long wave, medium wave and short-wave irregularity according to the wavelength, which affected the ride comfort, operation safety and wheel rail noise. Karis [4] analyzed the relationship between the measured vehicle vibration response and the track irregularity which showed that the correlation between track gauge irregularity and wheel rail lateral force was not strong, while the correlation between track vertical profile irregularity and vertical force was strong. Li et al. [5] analyzed the measured track irregularity data of Qinhuangdao-Shenyang passenger dedicated line and Wuhan-Guangzhou passenger dedicated line, and the results show that the track vertical profile irregularity and alignment irregularity spectrum curves are changing continuously, and the irregularity wavelength range is 0.4-125m. Chen et al. [6] analyzed and calculated the power spectral density of track irregularity measured data of Qinhuangdao-Shenyang passenger dedicated railway track, and obtained the parameters of fitting spectrum expression by using the least square fitting optimization algorithm. Chen et al. [7] calculated the power spectral density of high-speed railway track irregularity, the research shows that the high-speed railway vertical profile irregularity has a significant impact on the vertical acceleration of the car body and the unfavourable wavelength range of cross-level irregularity to the vertical and horizontal vibration of the car body is 2.0-3.5m. Zhang et al.
[8] analyzed the influence of four basic types of random irregularity on the straight-line and curve-line operation performance of high-speed trains. Wang et al. [9] compared the track spectrum of Qinhuangdao-Shenyang Railway with that of Germany in terms of the power spectrum density, time sample and the dynamics performance. Gao et al. [10] analyzed the irregularity spectrum of ballastless track of high-speed railway in China from the perspective of power spectral density, time samples and dynamic impact, and compared it with that of high-speed railway in Germany. Wang et al. [11] built the vertical coupling dynamic model of train ballastless track subgrade system by the basic principle of wheel rail system dynamics, calculated and analyzed the dynamic response of vehicle and track system under three kinds of irregularity spectrum, and compared and analyzed the influence of different irregularity spectrum on train track system. Shi et al. [12] analyzed the measured data of vibration acceleration of key components of 300km/h high-speed train, and studied the changes of riding stability and riding comfort with different line conditions, different train running speeds and other parameters.

In this paper, the difference of power spectral density between high-speed railway tracks and existing railway tracks is compared. The nonlinear dynamic model of high-speed EMU vehicle is built to simulate and analyze the influence of different railway tracks on vehicle dynamics performance which includes vehicle Sperling index, frame acceleration when the vehicle runs in straight tracks and lateral wheelset force when the vehicle runs in curve tracks.

2. THE DYNAMICAL MODEL OF VEHICLE

The high-speed train is a complex multi-body system, which not only has the interaction force and relative motion between the various components, but also the interaction between the wheel and the rail. In order to better simulate the running performance of the high-speed train, a vehicle model is built in Simpack multi-body dynamics simulation software based on the parameters of a current high-speed train. The model consists of a carbody, two bogies, eight axle-boxes and four wheelsets. The axle-box can only rotate around the axle of the wheelset, and the others have full degrees of freedom. The dynamics model of the train with three vehicles is plotted in Figure 1, and the equation of motion for the train system can be presented by [13],

\[ M\ddot{x} + C\dot{x} + Kx = P(\dot{x}, \ddot{x}, x) + Te \]  

(1)

![Figure 1. The dynamical model](image)

3. COMPARISON OF HIGH-SPEED DEDICATED AND EXISTING RAILWAY TRACKS

3.1. Power spectral density analysis

In order to compare the difference of track spectrum of different lines, the track spectrum of Qingdao-Jinan line (abbreviated as QJL), Qinhuangdao-Shenyang line (abbreviated as QSL), Wuhan-Guangzhou line (abbreviated as WGL) and Beijing-Tianjin line (abbreviated as BTL) is analyzed. Among them, Qingdao-Jinan line, Qinhuangdao-Shenyang line are existing railway lines, Wuhan-Guangzhou line and Beijing-Tianjin line are high-speed dedicated railway lines. The analysis includes the track vertical profile, cross-level, alignment and gauge irregularities. The analysis results are shown in the figure 2.

As can be seen from the Figure 2:
- The vertical profile irregularity of high-speed dedicated spectrum is consistent with the track cross-level irregularity.
The power spectrum of vertical profile irregularity and alignment irregularity of high-speed dedicated railway lines is generally better than that of the existing railway lines in the middle and long wave part. The track gauge irregularity of the existing railway lines and the high-speed dedicated railway lines is relatively consistent. The cross-level irregularity of the high-speed dedicated railway lines is better than that of the existing railway lines in the middle and long wave part, and the cross-level irregularity of the existing railway lines is better than that of high-speed dedicated railway lines in the short wave part.
3.2. Dynamics performance analysis

In order to compare the dynamics performance of vehicles running on the high-speed dedicated railway lines and the existing railway lines, the lateral acceleration on the bogie frame and the Sperling index of vehicle running on different track spectrum are simulated and analyzed. The track spectra used are BTL, WGL, QJL, QSL. Vehicle running speed is set to 350km/h and 160km/h. The mean value of vehicle Sperling index, the maximum value and root mean square value of frame lateral acceleration are analyzed. The analysis results are shown in the Figure.3 and Figure.4.

As can be seen from the Figure.3 and the Figure.4:

- At the same speed, the horizontal and vertical Sperling indexes of the vehicles running on the high-speed dedicated railway lines are better than those running on the existing railway lines under the tangent track cases.
- At the same speed, the maximum and root mean square values of the lateral and vertical acceleration of the bogies of the vehicles operating on the high-speed railway lines are better than those of the vehicles operating on the existing railway lines under the tangent track cases. (At the low speed, the maximum and RMS values of the lateral acceleration of the two bogies running on the high-speed railway lines are 59.7% and 24.6% of the corresponding values of the bogies running on the existing railway lines respectively, accordingly, the maximum and RMS values of vertical acceleration are 49.1% and 89.8% respectively; at high speed, the corresponding values are 54.2%, 32.3% and 27.6%, 55.3% respectively.)
3.3. Curve passing performance analysis

According to the provisions on the curve radius of high-speed dedicated railway tracks, mixed passenger and freight railway tracks and intercity railway tracks in TB10098-2017 code for design of railway line, and based on the specific conditions of the actual line, the track geometry and go over speed of vehicle listed in the Table.1 are chosen as numerical simulations. The lateral wheelset force (sum of the lateral wheel force of right and left wheels on the wheelset) is simulated and analyzed when the vehicle passes through the curved tracks. As can be seen from the Figure 5. With the decrease of the radius of the curved track, the lateral wheelset force increases gradually and it is a potential safety issue when a high-speed dedicated EMU was operated at an existing track with sharp curvature. A solution
for that is an adjustable wheelset steering stiffness shall be employed to provide a relative soft steering when the train runs from a high-speed railway to a conventional railway.

TABLE 1. PARAMETERS OF DIFFERENT LINE CONDITIONS

| Cases | Curve radius (m) | Transition curve (m) | Superelevation (mm) | Vehicle speed (km/h) |
|-------|------------------|----------------------|---------------------|---------------------|
| 1     | 1500             | 230                  | 175                 | 160                 |
| 2     | 2200             | 300                  | 175                 | 200                 |
| 3     | 3200             | 490                  | 175                 | 250                 |
| 4     | 5000             | 585                  | 175                 | 300                 |
| 5     | 7000             | 680                  | 175                 | 350                 |
4. CONCLUSIONS

A multi-body dynamic model of a high-speed EMU is built and its dynamics behavior is studied. The difference of dynamics performance when the vehicle running on the high-speed dedicated railway tracks and the existing railway tracks is analyzed. The following conclusions can be drawn.

- The power spectrum analysis shows that the overall situation of the track spectrum of the high-speed dedicated railway tracks is better than that of the existing railway tracks.
- At the same travelling speed, the dynamics performance of the vehicles on the high-speed dedicated railway tracks are better than those on the existing railway tracks for tangent track cases.
- With the decrease of the radius of the curved track, the lateral wheelset force increases gradually and it is a potential safety issue when a high-speed dedicated EMU was operated at an existing track with sharp curvature. A solution for that is an adjustable wheelset steering stiffness shall be employed to provide a relative soft steering when the train runs from a high-speed railway to a conventional railway.

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