[Research on the Operation Safety of High-speed Train under Strong Wind Based on Simulation Model]

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INTRODUCTION

With the increase of the running speed of the train, the deterioration of the aerodynamic performance of the high-speed train under the strong wind seriously affects the lateral stability of the train, which may lead to the derailment of the train. Because of affecting the safety, stability and comfort of the train, the strong wind has become one of the factors in restricting the safe operation and speed boost of high-speed train. Based on high-speed railway wind test data and dynamic performance data of EMU (such as derailment coefficient, rate of wheel load reduction and axle lateral force), the relationship between the wind speed and the dynamic performance of the train under different operating speeds is established to analyze the influence of strong wind on the safety of high-speed train so as to provide a scientific basis for operational rules under the conditions of the wind.

GALE MONITORING OF HIGH-SPEED RAILWAY

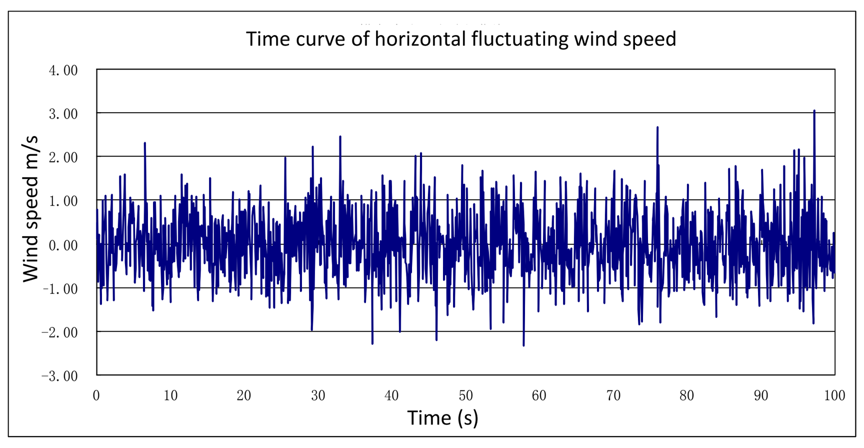
■ In order to study the influence of wind speed and wind direction on the operation safety of EMU, it is necessary to monitor the wind speed variation along the high-speed railway.

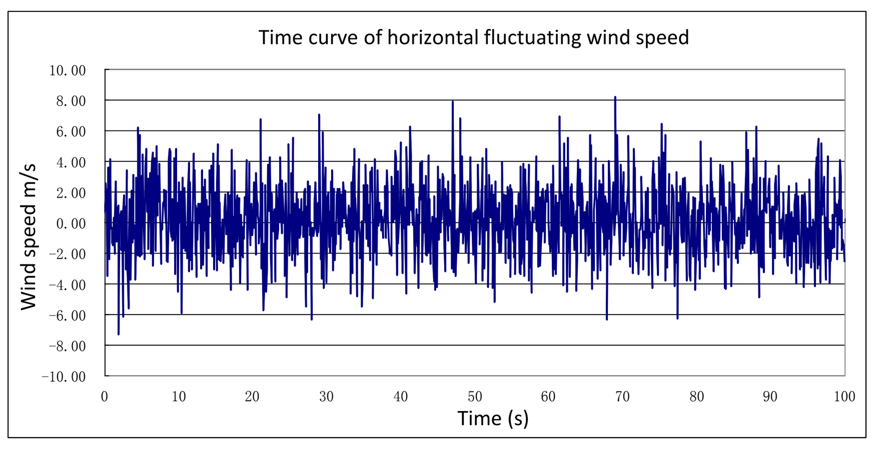
■ In the select-site of the wind test section, both frequency of occurrence of strong winds and the representative monitoring area is mainly considered. the test sites are selected in the open area, high embankment and viaduct with strong wind.

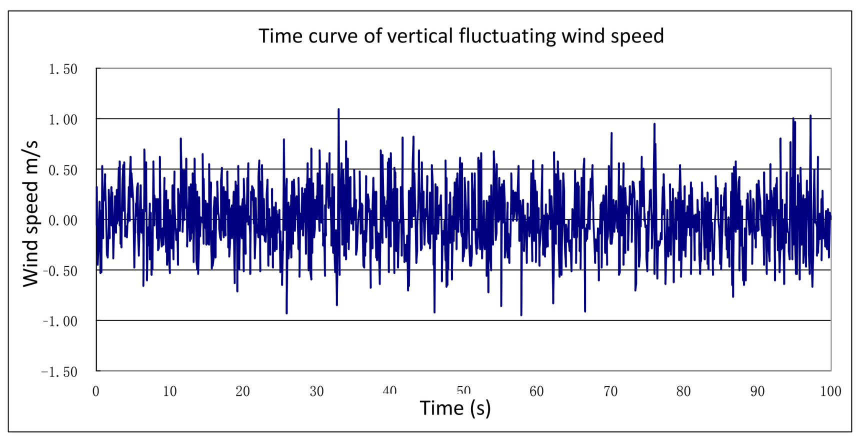
■ The test trains are CRH2 and CRH3 EMU. The ambient wind speed and the corresponding wind direction data and dynamic offset data were collected when EMU passed monitoring point at 180km/h, 200km/h, 220km/h, 230km/h, 240km/h, 250km/h, 260km/h and 270km/h.

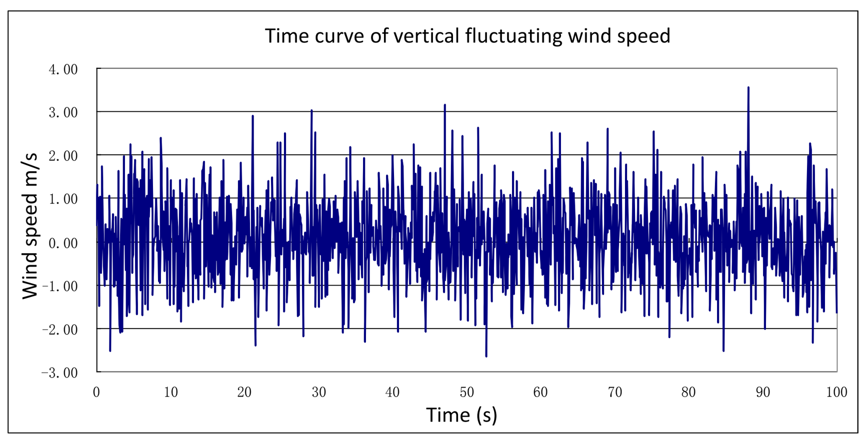
GENERATION OF FLUCTUATING WIND FIELD

In order to ensure the full vibration of the vehicle, the length of the wind field is 5km, the fluctuating wind field is simulated by average wind speed 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 27.5 and 30 m/s using the vehicle-track-bridge coupled vibration analysis software. The action time of wind field is 100s, time interval is 0.08s, and sample spacing of wind field is 3m.







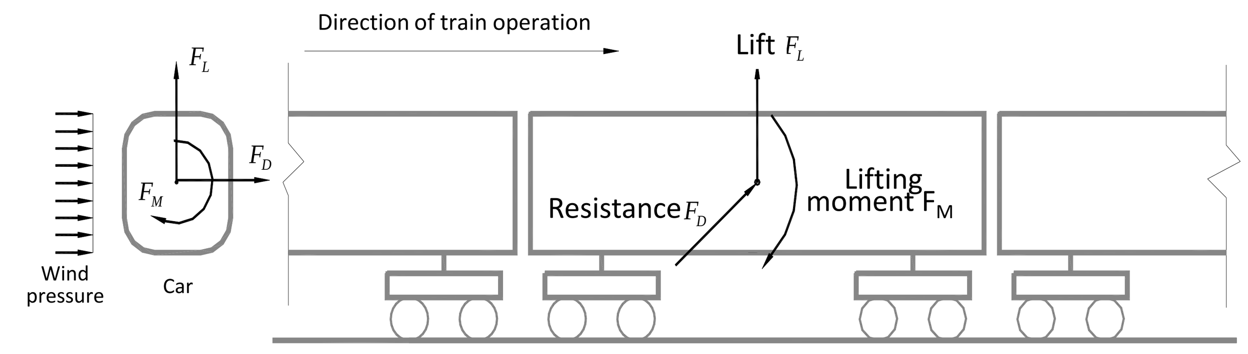


Time course of fluctuating wind speed in the middle of wind field (Average wind speed = 7.5m/s)

Time course of fluctuating wind speed in the middle of wind field (Average wind speed = 25m/s)

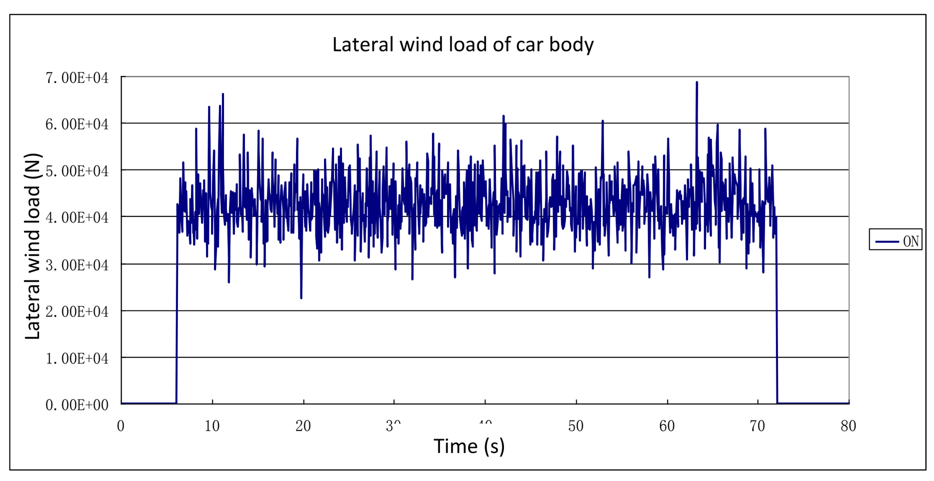
ANALYSIS AND CALCULATION OF TRAIN WIND LOAD

The wind load of vehicles under the action of natural wind is mainly composed of two parts: one is static wind load, the other is buffeting force caused by the action of fluctuating wind. The figure below shows the wind load on the vehicle.



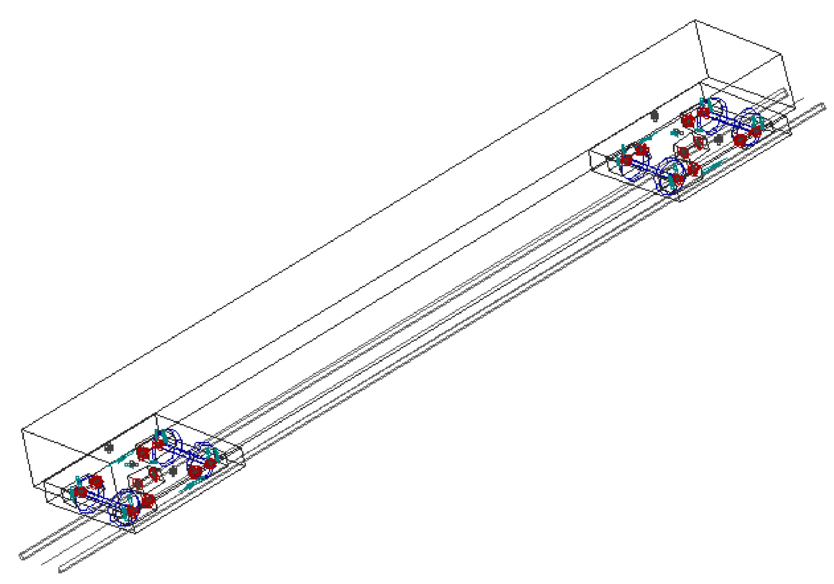
The lateral winds, vertical winds and torques of the car body and the wheelset are calculated, and used as an additional external load when the wind-vehicle-track coupled vibration analysis is carried out using NUCARS software. In the calculation, 0.5 km in the windless area is set on both sides of the wind field. In the windless area, the train vibration is mainly affected by the line state, and after entering the wind area, the vibration is affected by the line state and the wind load.

The following figure shows the time curve of the lateral wind load of the car body under the wind speed of 25m/s when CRH 2-300 EMU is running at the speed of 300 km/h. The curve shows that the lateral wind load of the car body is 0 in the windless area, once entered the wind area, the wind load will increase rapidly and will form a moment of impact on the car body.

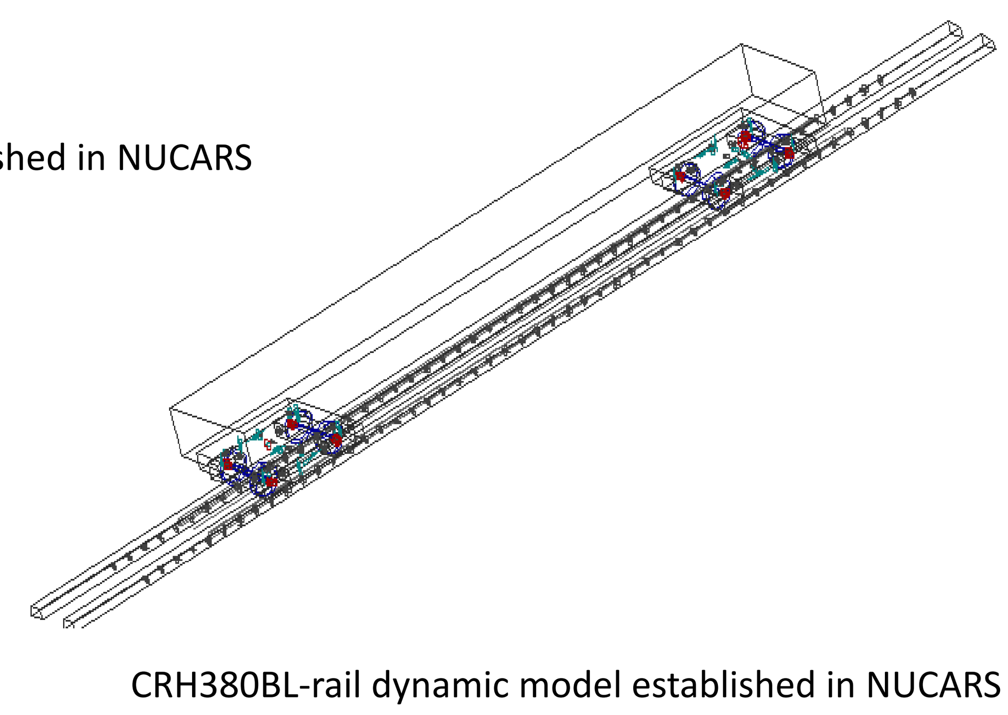


WIND-VEHICLE-TRACK DYNAMICS SIMULATION MODEL

The CRH2 trailer and CRH3 of Chinese High-speed Electric Multiple Unit (EMU) are modeled by NUCARS software, and the vehicle is divided into 15 rigid bodies. The nonlinear coupling dynamic model of EMU-track with 86 degrees of freedom is established.



The CRH2 vehicle model established in NUCARS



CRH380BL-rail dynamic model established in NUCARS

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DYNAMIC SAFETY EVALUATION STANDARD

① Derailment coefficient $D_q = \frac{Q}{P}$

P and Q are the vertical forces and lateral forces acting on the rails when the wheels climb the rails respectively. When Q/P> 0.80, stop speeding up.

② Rate of wheel load reduction $U_r = \frac{\Delta P}{\bar{P}}$

ΔP is the wheel load reduction, $\bar{p}$ is the average static wheel load. When two consecutive peaks of Δ p / p > 0.80 occur, stop speeding up.

③ Axle lateral force $H = Q_L - Q_R$

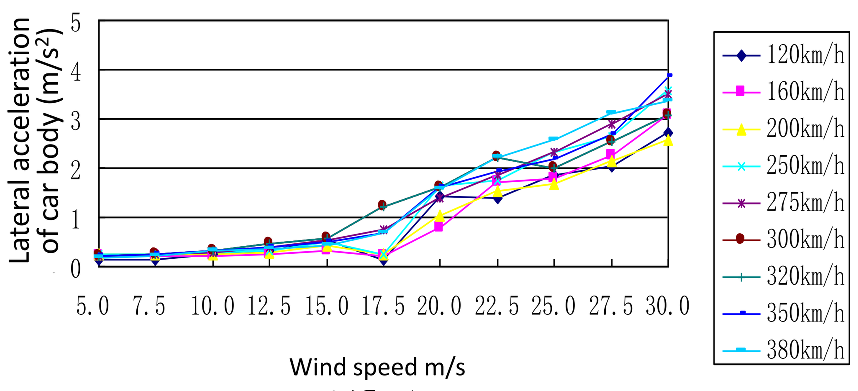
Q_L is the left wheel lateral force of the wheelset, Q_R is the right wheel lateral force of the wheelset. When the axle lateral force H> 10 + P_0/3, stop speeding up. The H limit value of the axle lateral force of CRH2 EMU is 48kN, and the H limit value of the axle lateral force of CRH3 EMU is 52.84kN.

④ Body acceleration

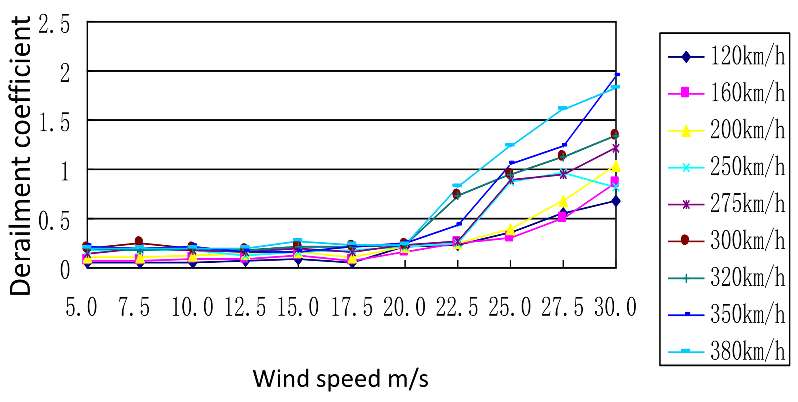
The lateral acceleration of body vibration $a_l \le 0.20$ g;
The vertical acceleration of body vibration is $a_v \le 0.25$ g

SIMULATION RESULTS AND ANALYSIS

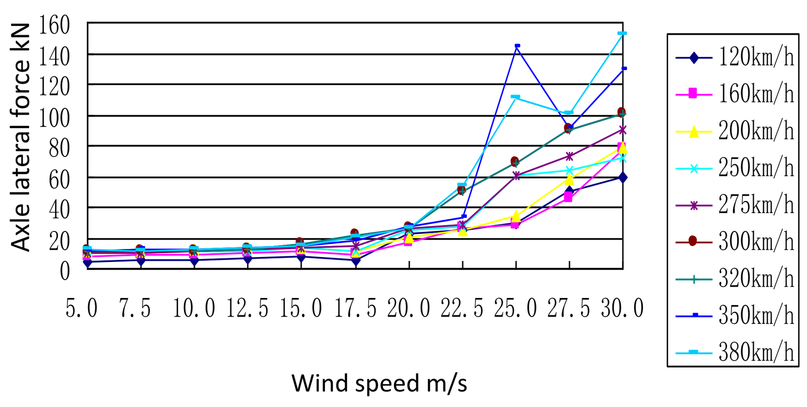
（1）CRH2 EMU



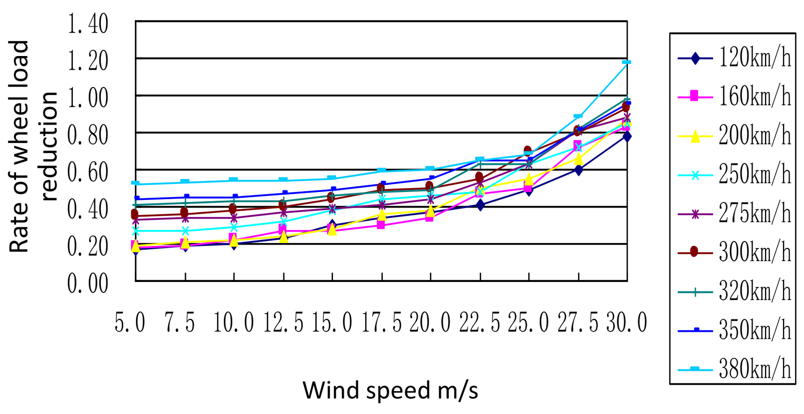
Influence of wind speed and train speed on lateral acceleration of car body



Influence of wind speed and train speed on derailment coefficient

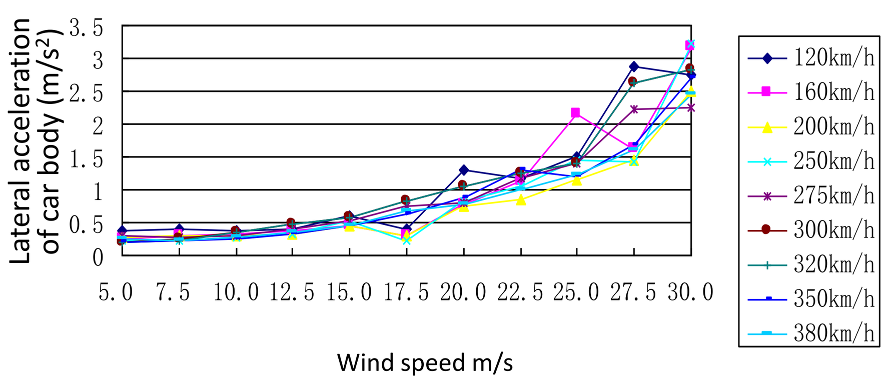


Influence of wind speed and train speed on axle lateral force

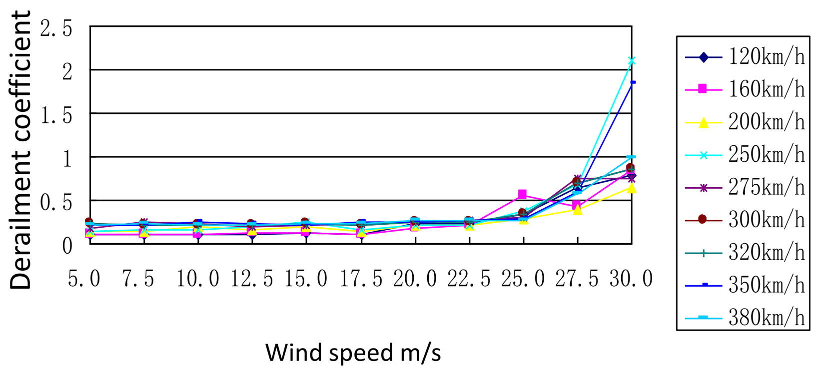


Influence of wind speed and train speed on rate of wheel load reduction

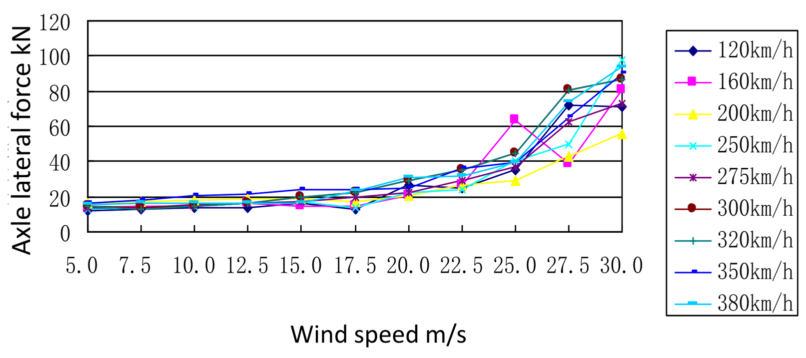
（2） CRH3 EMU



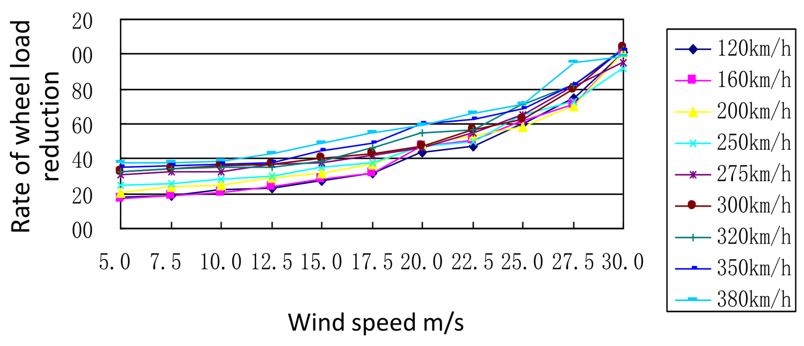
Influence of wind speed and train speed on lateral acceleration of car body



Influence of wind speed and train speed on derailment coefficient



Influence of wind speed and train speed on axle lateral force



Influence of wind speed and train speed on wheel load reduction

In contrast to the dynamic effects of winds on CRH2 and CRH3 EMU, when the wind speed reaches 22.5m/s, lateral acceleration of the car body of CRH2 with the speed of 300km/h and above exceeds 2.0m/s^2 , and lateral acceleration of the car body of CRH3 with the speed of 300km/h and above will reach the speed limit when the wind speed is 27.5m/s.

When the wind speed reaches 25m/s, the derailment coefficient of CRH2 at the speed of 250 ~ 380km/h exceeds 0.8 safety limit, the derailment coefficient of CRH3 does not exceed when the wind speed is less than 30m/s. When the wind speed reaches 27.5m/s, the axle lateral force of CRH2 at the speed of 250 ~ 380km/h and CRH3 at the speed of 275km/h and above exceed the safety limit. When the wind speed reaches 30m/s, wheel load reduction of CRH2 at the speed of 160 ~ 380km/h and CRH3 at the speed of 120km/h and above exceed the safety limit.

THE BASIS FOR DETERMINING THE STRONG WIND THRESHOLD

Determine the relationship between critical wind speed and train speed by lateral acceleration index

CRH2		CRH3	
Critical value of wind speed （m/s）	Train speed when lateral acceleration exceeds safety limit （km/h）	Critical value of wind speed （m/s）	Train speed when lateral acceleration exceeds safety limit （km/h）
17.5	The lateral acceleration at all speeds starts to increase linearly	-	-
22.5	300	22.5	The lateral acceleration at all speeds starts to increase linearly
25	250	27.5	275
27.5	120	30	120

Determine the relationship between critical wind speed and train speed by derailment coefficient index

CRH2		CRH3	
Critical value of wind speed （m/s）	Train speed when derailment coefficient exceeds safety limit （km/h）	Critical value of wind speed （m/s）	Train speed when derailment coefficient exceeds safety limit （km/h）
22. 5	380	–	–
25	250	–	–
30	160	30	120

Determine the relationship between critical wind speed and train speed by axle lateral force index

CRH2		CRH3	
Critical value of wind speed （m/s）	Train speed when axle lateral force t exceeds safety limit （km/h）	Critical value of wind speed （m/s）	Train speed when axle lateral force t exceeds safety limit （km/h）
25	300	–	–
27. 5	250	27. 5	275
30	160	30	less than 120

Taking into account the factors of lateral acceleration, derailment coefficient and wheel lateral force for CRH2 and CRH3, the critical wind speed is 22.5m/s when the train speed is 300km/h, the critical wind speed is 25m/s when the train speed is 250km/h, the critical wind speed is 27.5m/s when the train speed is 120km/h. The simulation results are basically consistent with the operational rules under the strong wind of high-speed railway in China's existing regulations when considering the safety margin factors.

CONCLUSIONS

When the wind speed of natural wind are collected from the wind monitoring system along the high-speed railway, the dynamic displacement data of EMU should be collected to determine the relationship between the critical wind speed and train speed through the lateral acceleration and derailment coefficient index.

The safety index of CRH2 and CRH3 under the conditions of different train speed and wind speed is analyzed by the wind-vehicle-track coupling dynamics model. The results show that the safety of CRH3 under strong wind is better than that of CRH2.