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Investigation of aerodynamic effects on the high-speed train exposed to longitudinal and lateral wind velocities

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ABSTRACT

The wind stability of the high-speed train has gained an increasing interest in the last few years. In this paper, an investigation of the effects of stochastic winds with longitudinal and lateral components on the high-speed train is described. The longitudinal and lateral wind time histories at the position of a moving vehicle, for a variety of wind directions, are first simulated. An algorithm for computing the unsteady aerodynamic load time histories is then derived for a moving vehicle. A typical railway vehicle has been modeled using the vehicle dynamic simulation package 'Simpack', and the unsteady wind loads of the same vehicle are applied to the vehicle model to investigate the dynamic response behavior. The simulated vehicle behavior is assessed against the indicator of load reduction factor, which indicates wheel unloading and therefore potential roll over. The characteristic wind curves (CWC) and its spread range are then obtained to evaluate the operational safety of the high-speed train. The results demonstrate that the operational safety of the high-speed train will be overestimated if the lateral wind velocity is not considered, especially for the small angles between vehicle and wind.

1. Introduction

The crosswind stability of the high-speed train has become a major issue of concern in recent years, mainly motivated by vehicle overturning and higher operating speeds. A considerable amount of work has been carried out by a number of researchers in UK (Baker et al., 2004; Baker 2003, 2010, 2013; Ding et al., 2008), Italy (Cheli et al., 2010a, 2010b, 2012; Bocciolone et al., 2008; Tomasini and Cheli, 2013), Sweden (Dierichs et al., 2007; Krajnović, et al., 2012), Germany (Hoppmann et al., 2002; Carrarini, 2007; Wetzel and Proppe, 2010) and China(Xu and Ding, 2006). Particularly, in the standard EN 14067-6, a deterministic methodology, based on the "Chinese Hat" wind gust model, to evaluate the dynamic response of a railway vehicle to cross wind action has been proposed. What is more, an outline of the stochastic wind model has been made in Annex J in the standard EN 14067-6.

The stochastic approach for reproducing the real wind–train interaction has been studied over the past few years. Cooper (1985) developed a random-process model for the turbulent wind with respect to a moving ground vehicle, and discussed the power spectral density and aerodynamic-admittance functions for unsteady side force. Xu and Ding (2006) presented a framework for simulating the interaction of vehicles with track exposed to unsteady wind force, and investigated the safety

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and comfort performance of the railway vehicle. Ding et al. (2008) simulated a train journey subject to one particular type of storm, and acquired the probability of train overturning for a variety of train speeds. Baker (2003, 2010) considered the nature of the fluctuating crosswind and set out the use of aerodynamic weighting function in obtaining the unsteady force time histories. Furthermore, a revised methodology was proposed, which can be used for train authorization and route risk analysis(Baker, 2013). Cheli et al. (2012) reproduced the wind speed space-time distribution through a stochastic process, set up the algorithm for the unsteady aerodynamic forces, and defined the characteristic wind curves (CWC) to evaluate the aerodynamic performance of a train in terms of safety towards crosswind. In most research mentioned above, only the longitudinal velocity fluctuation (the same direction of the mean wind speed) is considered with an assumption that the mean wind speed is normal to the train axis(the wind direction is 90°). The effect of the lateral velocity fluctuation on the aerodynamic force was not taken into account, although it can be expected to be of some significance. Yu et al. (2014) investigated that the consideration of the lateral wind velocity is not necessary when the mean wind speed is normal to the train axis. Nevertheless, the result only shows a kind of special circumstances in reality, which may not be applied to other wind directions.

Therefore, it is the purpose of the present paper to address the issues associated with work mentioned above. In Section 2, time histories of longitudinal and lateral components of the stochastic wind velocity at the position of a moving train are simulated based on the Cooper theory and harmonic superposition method, for a range of wind directions. In Section 3, an algorithm for computing the time histories of unsteady aerodynamic loads is presented. In Section 4, the vehicle system dynamic model with measured track irregularities is set up to simulate the dynamic response of the high-speed train exposed to aerodynamic load time histories. In Section 5, the results in the time domain are investigated.

2. Numerical simulation of stochastic winds

Fig. 1 shows the reference system used for the definition of the wind speed distribution in the present paper. The x–y plane is parallel to the top of the track. The y-axis is contrary to the train speed v, and the angle between the mean wind speed $\overline{w}$ and the rail is named wind direction α. The stochastic wind velocity consists of three orthogonal fluctuating components, which are the longitudinal component w'_x (the direction of the mean wind speed), lateral component w'_y and vertical component w'_z, respectively. In a strong crosswind scenario, the lateral aerodynamic performances of the high-speed train will seriously deteriorate. As is shown in Fig. 1, both the longitudinal fluctuating component w'_x and lateral fluctuating component w'_y will produce a wind velocity component perpendicular to the train, which has a significant impact on the lateral stability of the high-speed train. Therefore, the longitudinal and lateral wind velocities are taken into account in the present paper.

In order to precisely investigate the unsteady aerodynamic loads, a more realistic wind field needs to be simulated. Some investigators have carried out such a procedure by numerical simulating wind time histories at a large number of points, separately by short distances, along a track, using complex methodologies to ensure that the time series at each point have the correct spectral characteristics, and correlations between the time series at adjacent points have statistics that are consistent with those measured at full scale (Ding et al., 2008; Cheli et al., 2012). This approach proved to be robust and easy to use, although very computationally intensive, with the result that either only short sections of track could be simulated, or that the simulation points had to be widely separated (Baker, 2010).

However, in this paper, we take a different approach, which has been used by other investigators (Cooper, 1985; Baker, 2010; Yu et al., 2014). In this approach, only one wind time series is to be simulated, corresponding to the wind velocity at

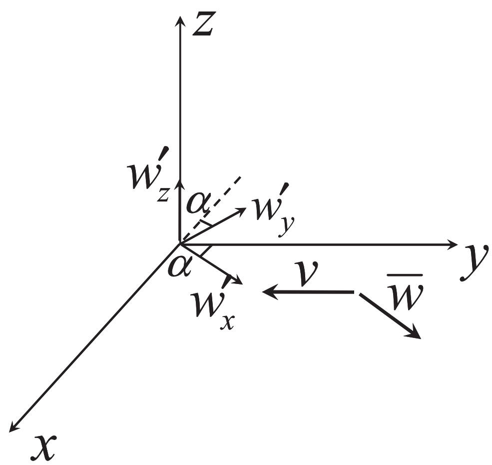

Fig. 1. Coordinate system.