Investigation of in-train stability and safety assessment for railway vehicles during braking

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Abstract

In-train stability of railway vehicles has becoming a major concern for railway vehicles, which refers to the jackknifing behavior of couplers under large in-train forces. For the train to train rescue scenario, braking induced impacts from couplers can adversely affect the dynamic performance of the coupled train. It is indicated from field tests that in-train forces if combined with large rotational angles of couplers can produce vertical components, which will further lead to the interference of adjacent car bodies and structural damages. In this paper, the dynamic model of the train and coupler system is developed. The model verifications are conducted by comparing the calculated responses with the tested results. The safety indices are formulated on the basis of which the running safety of the coupled train is evaluated. The propelling test in the laboratory is conducted to reproduce the coupler jackknifing behavior. The quasi-static analysis and anti-jackknifing mechanism under compressing in-train forces are analysed. Parametric studies are then conducted to propose some limitations for the application of train to train rescue. It is indicated from numerical and testing results that the decrease of the braking deceleration or a limitation of the free rotational angle of couplers is beneficial to lower the amplitude of braking induced impacts.

Keywords: In-train stability; Train to train rescue; Braking; Coupler jackknifing; Dynamic model; Test verification; Safety analysis; Force states; Laboratory experiments; Braking deceleration; Coupler free rotational angle

1. Introduction

Once a train is disabled in a high speed railway line, an assisting locomotive is traditionally used to rescue the disabled train. In order to increase the efficiency of train rescue and restore line operating orders quickly, train to train rescue is commonly used nowadays. Then the emergency couplers are specially designed to make the mechanical connections between different types of couplers possible [1]. However, as the disabled train is out of the ability of braking, the application of braking forces by the assisting train will generate longitudinal in-train forces and may lead to the so called “coupler jackknifing” behaviour. Jackknifing means the folding of an articulated vehicle or coupler, such that it resembles the acute angle of a folding pocket knife. If two vehicles are connected with a pair of couplers, the trailer vehicle can push from behind until spinning around or limited by boundaries. In fact, the rotations of the coupler with respect to the lateral or vertical pins are free. Thus, the coupler jack-knifing behavior reflects the relative motions between adjacent car bodies. This may be caused by equipment failure, improper braking, or adverse track excitations. In consequence, the lateral or vertical force components of in-train forces may affect the running safety of the coupled train [2].

In the field of heavy haul trains and locomotives, derailment accidents due to coupler jackknifing under buff forces were also reported in literatures. In recent years, the Transportation Safety Board of Canada (TSB) has investigated a number of rail accidents, in which coupler jackknifing under longitudinal in-train buff forces was a contributing factor [3]. In the Association of American Railways (AAR), studies of the in-train stability for freight cars date back to 1955 [4]. A prototype buff and draft car was designed, constructed and tested so as to determine the maximum lateral load that can be applied safely. In order to analyse the coupler angle on curved tracks, the Coupler Angling Behavior Software was also developed [5]. McClanachan et al. [6, 7] pointed out that longitudinal train dynamics can be divided into longitudinal-rotational, lateral and vertical dynamics. The combination of in-train forces and coupler angles produce lateral or vertical force components, which could lead to the increase of derailment coefficient and wheel unloading ratio. Cole et al. [8] took the coupling-free slack and nonlinear characteristics of buffer into consideration to study the coupler jackknifing and stringlining problem. It is also known that lateral force components and impacts from couplers can adversely affect wagon stabil-
ity [9]. It was reported that the coupler lateral-rotational behavior contributed a lot to gauge widening and rail rollover derailments under braking forces [10, 11]. Luo and colleagues [12, 13] have focused a lot on the investigation of coupler stability mechanism and the dynamic modeling of different types of couplers.

As the in-train stability of vehicles is of importance to the safe operation, some standards or technique specifications have been formulated. For a new vehicle design in AAR, it is recommended that an analysis should be made for a 250000-pound sustained buff and draft load, on a 10-degree curve or tighter, and a coupling arrangement with at least one additional vehicle which provides the longest possible truck base and overhang [14]. In Australia, the standard AS7509.2 [15] describes the method to evaluate whether the lateral component of longitudinal train forces in curves will be sufficient to cause wheel lift on rolling stock and subsequent derailment. During the in-train stability test on curved tracks, any wheel lift or flange climb lifting the centre of the tread off the rail head by more than 10 mm constitutes failure. In Europe, it is also recognized that longitudinal forces within trains have the potential to increase the risk of derailment when negotiating curves [16]. For conventional trains this risk is regarded as low. In the case of freight vehicles the procedure defined in UIC 530-2 shall be used. The permissible longitudinal compressive forces are determined by carrying out propelling tests on a S-shaped curve with the radius of 150 m [17].

In general, most of the current works are focused on studying the longitudinal dynamics of freight cars or locomotives on curved tracks. However, the coupler vertical jackknifing behavior and operating safety assessment for the train to train rescues, especially for high speed trains, is more significant. In this paper, the coupler vertical jackknifing behavior occurring in the field test of train to train rescue is introduced. The in-train forces are generated due to the application of braking by the assisting train. The longitudinal forces if combined with coupler rotational angles can produce vertical force components which affects the running safeties of the coupled trains. The dynamic models of typical train to train rescue scenarios are developed by using the simulation package SIMPACK. The calculated responses, e.g. the in-train forces, vehicle decelerations, wheel unloading ratio, pitch angles, etc., are also verified by field test results. The safety analyses for train to train rescue scenarios are then carried out. The propelling test in the laboratory is conducted for two coupled couplers to reproduce the coupler jackknifing behavior. The quasi-static geometry and force analyses and anti-jackknifing mechanism under compressing in-train forces are conducted. The influences of some basic parameters on the coupler jackknifing are studied. Parametric studies are then conducted to propose some limitations for the application of train to train rescues.

The objective of this paper is to introduce the so called in-train stability problem, a new phenomenon under the braking condition. The investigations are conducted by the field test, numerical simulations as well as laboratory experiments so as to give insight into its mechanism and consequent effects. Some measures or recipes are discussed to prevent the potential development of the jackknifing from both the quasi-static equations and dynamic computations.

2. Coupler angling behavior in field test of train to train rescue scenario

There exist different forms of coupler systems in the railway vehicles, which vary in mechanical structures, working mechanisms and buffer characteristics, etc. In the field of high speed trains, the Shibata coupler used for Shinkansen vehicles and the Type10 coupler for ICE, TGV and AVE vehicles are two of the most representative ones. Japanese Railway (JR) has widely standardized on the Shibata coupler, initially developed by a Railway engineer, Mamoru Shibata in the 1930’s. Fig. 1(a) shows the mechanical illustration of the Shibata coupler, included by the coupler body, coupler yoke, circular pins and some accessory components. The part with free rotations about the pins is called coupler body, while the whole section between the pins and the carbody is called yoke. The circular pins allow the coupler body’s free rotations relative to the yoke when negotiating horizontal or vertical curves. The yoke is supported by beams and limited by two anti-jumping beams. Relative movements or rotations are allowable due to the slacks and elasticity of these beams. Besides, the Scharfenberg coupler is a commonly used type of fully automatic railway coupling, which is designed in 1903 by Karl Scharfenberg in Königsberg, Germany. This coupler is superior in many ways to other couplers because it makes the electrical and the