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Traction, forces, wheel climb and damage in high-speed railway operations

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ABSTRACT

This paper summarizes the analysis of roughly 6 h of data from four instrumented wheelsets running at speeds of up to 240 km/h on the same Amtrak Acela trainset. Comparisons are made between power car and coach car traction values, *L*/*V* ratio, and damage (wear and RCF). The propensity for wheel climb is found to be roughly the same for power car and coach car wheels. The wear and RCF damage, as evaluated through the Tγ index, is about 50% higher for the two power car wheelsets than for the two coach car wheelsets. The peak traction coefficient on the Amtrak system is measured to have a value of about 0.65 at low speeds, declining to about 0.22 at 200 km/h. These levels are much higher than those found in the literature for high-speed trains.

1. Introduction

Understanding creepage and forces at the wheel/rail interface is an ongoing quest for many contact mechanists. Increasingly elaborate models of vehicles, track, wheel/rail contact, materials and interfacial layers are being developed to evaluate the wheel/rail forces and thereby explain the phenomena of corrugation, wear, contact fatigue, hunting, noise, vibration and other wheel/rail issues. But often this work takes place without the benefit of field data for the model validation.

The last decade has seen a proliferation of devices for analyzing wheel/rail performance, with lateral force detectors, angle-of-attack systems and ride-quality meters proving particularly useful in measuring vehicle–track performance. But for studies of wheel/rail contact, arguably the most useful investigative tool is the instrumented wheelset or IWS.

2. The instrumented wheelset

To make an IWS system, the wheel plate of an otherwise standard wheelset is machined to remove as much excess metal as possible, i.e. remove stiffness from the system and make the wheels as flexible as possible within the bounds of safe operation. Finite element analysis of the resulting wheel is used to obtain a strain map of the plate and identify the appropriate locations for strain measurements. Strain gauges are applied to the inside and outside of the wheel plate and hub (Fig. 1) for measuring the vertical, lateral and torque values for each wheel. The strain bridges are properly connected and then wired through a hole in the axle to a spinning amplifier mounted on the axle end. The signals are transferred from the axle to the carbody through a multi-channel slip ring device.

Eleven channels of data are collected per wheel (four lateral, two vertical, four position and one torque). Data are collected at 500 Hz, analogue filtered at 100–125 Hz and then digitally filtered in the software at 25 Hz. The data includes the vertical load, lateral load, wheel torque and lateral position of the contact patch with respect to the wheelset taping line for each of the left and right wheel. The resulting signals show considerable "noise" which may or may not be real. For the purposes of this work, we "smoothed" the initial waveforms using a moving average of 100 points (0.2 s) and then extracted every 500th point (i.e. 1 point/s). This resulted in a data set of over 20,000 points for subsequent analysis.

The instrumented wheelset has seen a large number of applications including derailment investigations (e.g. [1]), studies to understand or validate track geometry standards [2,3], and measurements of bogie performance characteristics [4] often to compare modeling results with the measured forces. But with a few exceptions (e.g. [5–8]) the instrumented wheelset is generally not available to most researchers of the vehicle/track interaction. It is (currently) a relatively expensive tool to own or rent, and deployment is often onerous. But if the forces at the wheel/rail contact are to be measured, it is really the only method currently available.

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Fig. 1. Strain gauges placed on both sides of the wheel plate are used to measure strains which are then converted into vertical, lateral and longitudinal forces at the wheel/rail contact. A protective coating is applied over the gauges prior to deployment.

The high-speed Acela trains running on Amtrak's Northeast Corridor are required each year to undergo a re-qualification test to ensure that with wear and time, the assembly of components continues to operate safely. These tests include simultaneous measurements from four instrumented wheelsets—in this case two in a (non-tilting) power car and two in the adjacent (tilting) coach car (Fig. 2). This 800 km run from Washington through New York and onwards to Boston is performed at speeds up to 240 km/h and (on a test basis) up to 225-mm cant deficiency. Under a program supported by the US Federal Railroad Administration, the IWS data provided by Amtrak from these four wheelsets is being analyzed to investigate a range of parameters having relevance to wheel–rail performance, modeling and testing. These include:

(A) The available adhesion at speeds ranging from 10 to 240 km/h. This is calculated primarily through evaluation of the net tractive force measured at the low wheel in curving where the creep force may be saturated. The possible influence of thermal and dynamic effects on the wheel/rail interfacial layer will be considered.
(B) The impact of braking and accelerating tractions. Their implications with respect to wear modeling, contact fatigue, lateral forces and wheel climb are discussed.
(C) The effect of cant deficiency on the longitudinal and lateral tractions in both the leading and trailing axles. The vectorial resultant of the creepage vector is considered in light of RCF crack generation and orientations observed in the field.

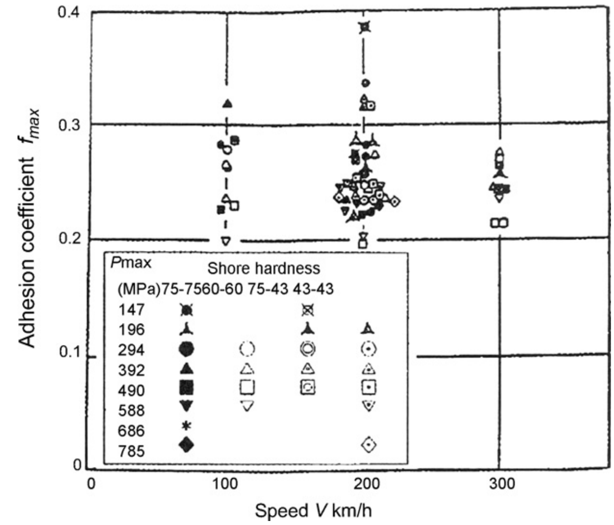

Fig. 3. Adhesion as a function of speed under dry conditions from Japan with a rail-roller rig [12].

3. Wheel/rail adhesion at high speed

3.1. Review

The adhesion between wheel and rail has been noted by Godet and others [9,10] to be highly dependent on the characteristics of the interfacial layer and the amount of moisture present. But the effect of speed on the interfacial layer is not clear. One suggestion is that with increasing speeds, thermal conditions modify the strength properties of the interfacial layer, decreasing its shear strength and reducing the available wheel–rail friction [11]. Various roller rig and field measurements have shown mixed results. Adhesion testing with a large-scale rail/roller rig under dry conditions found no effect of speed on the traction/creepage curve (Fig. 3)—though there was a large variation in measured values attributed to the chemistry of the surface films on the components [12]. Testing in China on a high-speed roller rig found the same strong effect of speed on adhesion for the water contaminated interface but unfortunately, limitations in the rig allowed dry testing only to 70 km/h [13] and a statement again that the dry adhesion is little affected by speed. These results contrast with European field tests in the 1980s with a "tribo-train" that produced a series of curves for adhesion based on "very limited" data (Fig. 4A). They suggested that the decline in adhesion with speed depends on the suspension characteristics and "wheel–rail dynamic interaction" [14]. A traction performance design curve based on roller rig testing is employed in China [13] that closely matches the European field measurements.

3.2. Analyzing the IWS data for adhesion

3.2.1. Tangent running

In quasi-static tangent running the component of traction associated with low levels of spin creep can be ignored and adhesion

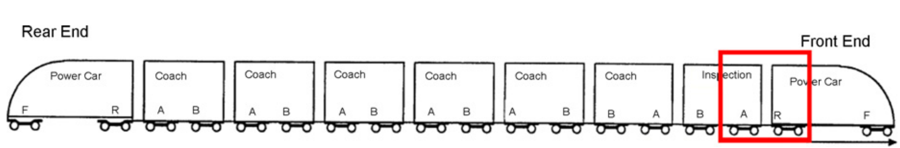

Fig. 2. An Acela train consists of power cars on each end with six, non-powered coach cars in between. For this test, Amtrak's high-speed inspection coach (10003) was inserted in the consist. The trailing bogie of the power car and lead bogie of the inspection car were all equipped with instrumented wheelsets.