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Non-uniformity in braking in coaching and freight stock in Indian Railways and associated causes

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ABSTRACT

Non-uniform braking of wheel sets in locomotives and coaches/wagons can have disastrous consequences e.g. from wheel locking leading to derailments or thermal cracking, particularly under emergency braking conditions. Currently, while rigorous testing is used to characterize brake block characteristics and brake application time, no methods exist to determine the "variability" in braking across the different wheel sets, e.g. from differences in brake block characteristics, brake rigging, and performance of distributor valves. In this work, temperature rise in railway wheels is used to gauge normalized heat input coming in to wheels from braking. Two sets of field trial data are used to investigate variability of braking: (i) continuous rim temperature data for locomotive wheels and (ii) one time measurement of wheel rim temperatures of *all* wheels. The data is used to pin point the causes for non-uniformity in braking and to characterize the extent of non-uniformity. Non-uniformity in braking is found to be particularly severe in freight trains as compared to passenger trains. Faulty distributor valves are seen to result in maximum braking effort on wheels that is as high as seven times that of average braking effort in freight trains.

1. Introduction

Braking systems in trains are very important from safety perspective and in many instances they also place restrictions on the peak train speed. Brake block characteristics, peak brake cylinder pressure, brake rigging, braking type (tread vs disc) and technique, i.e. vacuum, air, electro-pneumatic, or electronically controlled braking, influence braking distance, wheel and brake block temperatures, wheel slip, forces acting on couplers and draft gears, and nature of deceleration (smooth or "jerky"). Abnormal braking can result in undesirable consequences such as wheel flat formation from wheel slip, thermal degradation and excessive wear of brake blocks, generation of tensile residual stresses in wheel tread portion, excessive increase/reduction of wheel gauge and excessive forces on couplers/draft gears. A large majority of the trains currently operated by Indian Railways employ pneumatic, tread braking. While passenger trains use twin pipe (feed and brake pipe) system, freight trains commonly use single pipe system. This paper aims to quantify the existing state of non-uniformity in braking in passenger and freight trains operated by Indian Railways and identify underlying causes for the same. This would then be used to study the effect of non-uniform braking on wagon/coach wheel failure from gauge widening/condemning and thermal cracking in a subsequent paper.

In air braking systems, braking occurs whenever brake pipe pressure is reduced which causes pressurized air to move from auxiliary reservoirs to brake cylinders. Further, brake cylinder pressure, which controls the average brake load per wheel, is

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Nomenclature

IBV	independent brake valve
DBV	driver's brake valve
MR	main reservoir
AR	auxiliary reservoir
DV	distributor valve
IV	isolating valve
a	semi-axis length of the rail–wheel contact ellipse along the rail (mm)
b	semi-axis length of contact ellipse along the transverse to the rail (mm)
h	convective heat transfer coefficient (W/m^{2}K)
h_{wr}	thermal conductance at wheel–rail interface (W/m^{2}K)
h_{ax}	effective convective heat transfer coefficient used to model rail-chill effect in axi-symmetric analyses (W/m^{2}K)
ε	surface emissivity (−)
v_t	train speed (km/h)
BCP	brake cylinder pressure (bar)
t_{train}	train running time (h)
T_w	wheel rim temperature (°C)
ΔT_w	rim temperature rise of wheel (°C)
ΔT_s	temperature rise during synchronous braking (°C)
ΔT_m	mean rim temperature rise of the coach wheels in a train (°C)
Q_s	heat input to wheel during synchronous braking (°C)
KGP	Kharagpur railway station, India

directly proportional to the reduction in brake pipe pressure at least until it reaches a critical value. Since, brake pipe pressure is released by opening the driver's brake valve, typically located in locomotive(s), rate of reduction in brake pipe pressure is highest in locomotives and wagons/coaches closest to them (Murtaza and Garg [1] and Cantone et al. [2]). Consequently, braking of locomotive(s) and wagons/coaches doesn't occur simultaneously, i.e. there would be a time delay in braking. Typically, during train operation, brake pipe pressure is gradually decreased thereby causing gradual deceleration of all units and "soft" engagement of couplers and draft gears. On the other hand, whenever brake pipe pressure is suddenly reduced, e.g. during emergency braking, different units decelerate at different rates causing "hard" impacts which can create jerks and in some extreme cases cause derailments. In addition to time delay in braking, inherent to air braking systems, variability in brake block friction characteristics, distributor valve characteristics, brake rigging, and gap between brake blocks and wheels also affect the relative "braking effort" (energy dissipated during braking) experienced by the wheels. While assessing the effect of each of the aforementioned factors on braking effort separately is extremely challenging, time averaged relative braking effort experienced by different wheels can be compared using the approach stated in the following.

For tread braking, heat generated during braking goes into the wheel, brake blocks, rail, as well as ambient air. The problem of estimating wheel temperatures, for a given heat input at wheel–brake blocks and wheel–rail interfaces, is challenging due to constantly evolving contact. Nonetheless, a hybrid approach utilizing boundary element and finite element methods, may be used to accurately estimate the wheel temperatures after solving for the heat partitioning at the interfaces (Vakkalagadda et al. [3]). Even though, only a fraction of heat generated during braking is retained in the wheels, as shown in this paper, wheel temperature rise is nearly proportional to the braking effort, i.e. the heat generated during braking. Thus, time averaged braking effort for wheels can be compared by comparing temperature rise of the wheels. This approach has been adopted in this paper to characterize non-uniformity in tread braking in trains operated by Indian Railways.

Relatively few works exist on characterization of pneumatic braking and on measurement of wheel temperature and stresses. Several studies were conducted to check the efficiency of air braking systems in Indian railways. Murtaza and Garg [1], Murtaza and Garg [4], Murtaza and Garg [5] and Murtaza [6] studied the air pressure variation along the length of brake pipe during braking. Time lag for the brake pipe pressure reduction and time taken for filling up the brake cylinder in different wagons are calculated and validated. These studies gave the time lag in braking across the coaches/wagons of a train, but the study of overall performance of braking system and determination of non-uniformity in braking across the train is lacking. A few studies have been reported in literature to determine temperature evolution in wheels during tread braking. For instance, by using a numerical model Vernersson [7] estimated wheel and brake block temperature for both drag braking and stop braking. Wetenkamp et al. [8] measured the wheel temperature in the field with constant brake load and different brake shoes by fixing thermocouples in the wheel. Fec and Sehitoglu [9] measured the temperature rise in tread surface of wheels during braking by using pyrometers. However, measurement of temperatures on multiple wheels to characterize non-uniformity in braking was not reported. Several studies were reported to identify the effect of tread braking on wheels. Teimourimanesh et al. [10] calculated the change in wheel gauge during drag braking and stop braking with and without consideration of rail chill effect. Manka and Sitarz [11] described the occurrence of phenomenon 'thermal conicity' due to excessive thermal load on the wheel especially due to brake system