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A predictive model of energy savings from top of rail friction control

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ABSTRACT

In this paper the authors present a predictive model of train energy requirements due to the application of a top of rail friction modifier (TOR-FM) versus dry wheel/rail conditions. Using the VAMPIRE® Pro simulation package, train energy requirements are modeled for two sets of TOR-FM frictional conditions, one using full Kalker coefficients and the other by using a Kalker coefficient of 18%. Both scenarios use a top of rail saturated coefficient of friction of 0.35. Under both TOR-FM frictional conditions, train energy savings are shown for complete laps of the Transportation Technology Center Inc.'s (TTCI) Transit Test Track (TTT) loop, and also when isolating only the tangent section of the loop. However, the magnitude of energy savings varies greatly depending on the Kalker coefficient factor used, highlighting the need to model this relationship as accurately as possible. These simulation results are compared with data obtained from a field study, in which train energy savings of 5.3% (lap) and 7.8% (tangent) are shown due to the application of TOR-FM.

1. Introduction

1.1. Wheel/rail friction

Friction at the wheel/rail interface is understood to have significant impacts on wheel and rail wear, lateral (curving) forces, curve noise, and train energy (fuel usage) [1–3]. In recent years industry focus has been on the separate control of friction at (a) the gauge face/flange interface (traditional lubrication) and (b) the top of rail (TOR)/wheel tread interface. The latter requires special materials known as friction modifiers that provide (a) a controlled intermediate coefficient of friction (average $\mu = 0.35$ [4] as measured by a Salient Systems push tribometer) considered safe for braking and adhesion, and (b) a positive slope to the creepage/creep force curve beyond the point of creep saturation (referred to as positive friction) [5]. This paper describes modeling work aimed at better understanding the role and mechanisms of TOR friction control in reducing train energy requirements, and continues previous work presented in [6].

Friction between the wheel and rail should be considered as a function of creep (microslip). This relationship in turn is dependent on the properties of the interfacial layer between wheel and rail, the so-called Third Body [7]. The goal of friction control is to manipulate the composition of the Third Body to adjust the shear properties (yield strength) to achieve appropriate targets. Unfortunately, the subtleties of the creepage/creep force relationships under different frictional conditions are not well represented in current vehicle dynamics software packages.

1.2. Train energy and fuel consumption

Locomotive fuel consumption and technologies to reduce train energy are major focus areas for heavy haul freight operators. There are a number of published reports of the impact of TOR friction control (TOR-FM) on energy savings. Prior models have emphasized the impacts of reduced curving resistance, predicting relatively low absolute energy savings in low curvature track, i.e. that the absolute energy savings with TOR-FM is an exponential function of track curvature [3]. Recent work [8] has indicated that all three major data sets for heavily curved territory fall on the same exponential relationship. This suggests that in these territories the largest component of energy savings with TOR-FM originates from reductions in curving resistance (lateral forces).

Other results have suggested that significant energy savings are also achieved in areas of predominantly tangent track and shallow curvature [9]. These results deviate significantly from the relationship based on curve density described in [3,8]. As these territories represent the majority of the fuel consumption on heavy haul railways, it is important to provide a strong scientific underpinning to understanding and quantifying the effects of TOR-FM on train energy.

2. Mechanisms for energy savings in tangent/low curvature track

As noted above, one of the primary motivations for this work is the development of a practical understanding and modeling approach that allows for the prediction of energy savings in tangent and low curvature track due to friction control at the top of rail/wheel tread interface. In order to provide a working explanation for

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these results and the potential for an effective model, a hypothesis was formulated based on the potential influence of (a) inherent vehicle component misalignments and (b) persistent deviations from the neutral running position in tangent track. This study is part of an ongoing body of work aimed at evaluating the validity and potential applicability of the hypothesis.

Vehicle component misalignments, e.g. angular misalignments between axles in bogie, are a practical reality in freight railroad operating conditions. The three-piece bogies that are typically used in North American Heavy Haul freight are known to carry a potential for misalignment and/or slack in the mating of components in part due to the simplicity of the design (a strength from the standpoint of maintainability). The influence of this type of misalignment on energy spent at the wheel/rail interface was explored in [6].

The second component of the hypothesis is built around the potential for persistent deviations from the neutral running position in tangent track. After emerging from a curve, the final position and alignment of the bogie will be inherently variable due to (among other factors) the influence of sliding friction at the centerbowl. While steering forces will (assuming 'good' wheel/rail profiles) act to provide a positive steering moment to center the bogie, there will be the possibility of an equilibrium between these positive steering forces and the counteracting forces arising from the centerbowl and other components. In the presence of a persistent (albeit small) angle of attack, there will be a resulting persistent creepage at the wheel/rail interface and corresponding energy dissipation. By reducing friction levels through top of rail friction control, the dissipation of energy through this mechanism may be reduced, contributing to an overall reduction in effective rolling resistance and energy spent in moving the train.

3. Verification of proposed train energy model/savings

In order to better understand the train energy requirements under different top of rail/wheel tread interface frictional conditions and develop a predictive model of these energy requirements, a two part approach is employed in this study. In the first, the VAMPIRE® Pro simulation package is used to develop the predictive model of train energy requirements using the $T\gamma$ method outlined in Section 5.1 and fully derived in [6]. The simulation parameters were chosen to match closely with train energy data made available from a field study undertaken at the Transportation Technology Center Inc.'s (TTCI) Facility for Accelerated Service Testing (FAST). This field data is examined in the second part of the study. As such, for both parts of the study, the TTCI Transit Test Track (TTT) loop was utilized. The TTT loop consists of a 15 km loop with a 2200 m radius curve (with 50.8 mm cant), and two 1200 m radius curves (both with 114.3 mm cant), and a 3 km tangent track section with minimal grade as shown in Fig. 1. Train energy requirements were calculated for the entire loop and also for only the tangent section.

4. Field testing at TTCI-TTT

4.1. Proposed test procedure

For the aforementioned field study, which was undertaken on the TTT loop to evaluate the effects of TOR friction control on train energy requirements, a train consisting of two SD 70-M locomotives and 29 loaded 143-t gross weight coal hopper cars was used. An empty hopper car equipped with an onboard TOR friction modifier application system was placed directly following the locomotives which provided an air atomized spray of KELTRACK® friction modifier to the TOR surface. The mechanical train energy requirement was measured by means of an instrumented coupler placed between the TOR-FM system equipped car and the first loaded hopper car. Furthermore, Salient System push tribometers were used to measure TOR friction levels on both rails at two points in the loop, including upon entering the tangent section.

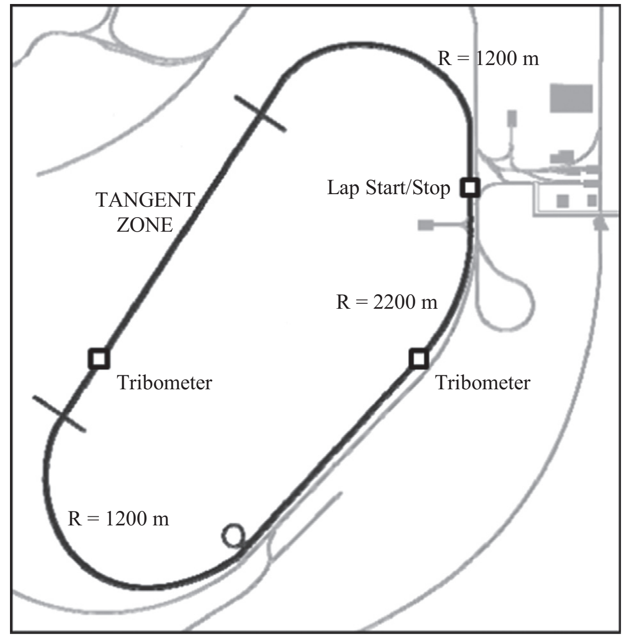

Fig. 1. TTCI Transit Test Track (TTT) loop showing track geometry and location of tribometer measurements used in field study.

4.2. Analysis of TTCI field results

During the initial test laps it was apparent, from both the tribometer and energy readings, that there was a poor transfer rate of friction modifier from the spray system to the top of rail surface. The primary reason was suspected to be high wind effects around the nozzle tip, causing only a portion of the total application rate of the atomized friction modifier to reach the rail. During subsequent laps, the nozzle wind skirt design was modified, resulting in better friction modifier deposition as shown by TOR coefficients of friction closer to those expected from previous tribometers measurements [4]. However, due to time constraints, this limited the number of valid laps for both the baseline dry and 'system on' to three for each condition set. Fig. 2 shows the average TOR COF value for each of the three dry laps and each of the three 'system on' laps.

Fig. 3 shows the mechanical energy calculated versus the average TOR COF for both the complete lap readings and the tangent section only after the wind skirt modification.

The average energy requirements for both the complete lap and isolated tangent section are shown in Figs. 4 and 5, respectively.

Table 1 shows the percent change in energy requirements between the dry baseline and friction modified laps.

5. Proposed train energy model

5.1. Energy expended at the contact area

The predictive train energy model used in this study is based on an integral of power dissipated at the wheel/rail contact area. For each wheelset the energy expended at the contact patch is influenced by the forward speed of the train, and the subsequent