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The influence of rail lubrication on energy dissipation in the wheel/rail contact: A comparison of simulation results with field measurements

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ABSTRACT

This work investigates the energy dissipation in a wheel/rail system with field measurements and friction work modeling. Friction and contact conditions are measured and analyzed in order to calculate the power saving of one vehicle running over a curve of a metro line. For modeling the contact forces, creepages and spin between the wheels and rails are determined via simulations of a train traveling in a curve of the track. Next the contact stress and the micro-slip in the contact area are computed from the forces, creepages and spin as well as the measured friction coefficient and profiles of wheels and rail. Three friction conditions are tested: dry, lubricated with a friction modifier and a postlubricated condition. The total frictional work is obtained by integrating local frictional dissipation over the contact area. The wear is also analyzed according to the $T\gamma$ method including the spin, in combination with Kalker's simplified theory, assuming that the wear is proportional to the frictional work. The frictional work is then related to the energy consumptions under the different friction conditions, which allows evaluating the effectiveness of the friction modifier and its influence on the wear of the wheel/rail system.

1. Introduction

Lubricants have been widely used in railway systems in order to increase the lifetime of the wheel and rail, as well as to decrease the maintenance and operating expenses. There are two types of lubrication systems: stationary, which is installed along the tracks, and on-board, which moves on a train and the lubricants are often applied to the flange of the wheels. Lubrication has traditionally been employed to reduce friction and wear. Nowadays at the top of the rails a special type of lubricants is applied to ensure a stable coefficient of friction, which is required in operation conditions such as accelerating and breaking. This kind of lubricants is called friction modifiers (FM). FM are lubricant greases with a high content of abrasive particles which produce microabrasion in the contact keeping the friction coefficient at a proper value for the system [1]. According to [2], an appropriate value of the friction coefficient is 0.35, but this optimum value depends on the characteristics of the systems, such as, the axle load.

Implementing effective lubrication strategies on small radius curves allows for a reduction in wheel's wear, rail's wear and noise level. A research carried out in the UK by the Engineering Research Program in 2003 [3] shows that by using lubricants the rail life can be increased by a factor of 2, wheel life by a factor of 5 and the re-profiling intervals can be also extended by a factor of 4.

As mentioned above, it is possible to reduce the operation costs through the implementation of lubrication systems. According to Reddya et al. [4], a 12 MGT transportation system can save around 2.4% for 0–300 m curves, 9.1% for 300–450 m curves and 15.5% for 450–600 m curves, by proper planning of the intervals for rail grinding and using an adequate lubrication for its interface.

A research carried out by Braghin et al. [5] allowed predicting the wheel profile evolution through numerical modeling. Results obtained from multibody simulations were used in a wear model based on Derby wear indexes, where the wear coefficient was calculated from experimental results obtained with a twin disc test machine. The wear prediction model was validated using full-scale experimental tests carried out on a single mounted wheelset under laboratory conditions and implemented to predict the evolution of the wheel profile during standard service in an ETR500 Italian high speed passenger vehicle.

Ignesti et al. [6] performed a research using Simpack Rail to develop a predictive model for the wheel and rail evolution due to wear, in this work the Derby wear indexes and the results found by Braghin are used in order to calculate the wear rates. Ignesti et al. proposed a model based on a discrete process with different

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time scales between the wheel and the rail. This methodology and a 3D contact model previously developed by the authors have been applied in [7] to estimate the evolution of the wheel and rail profiles due to wear for a complex railway network using two approaches, a track statistical to obtain relevant results in a reasonable time and a complete railway line.

At the Metro of Medellin the energy-related operation costs reached US$ 9.34 million per year in which US$ 6.74 million corresponds to traction of the vehicles. The study of the energy consumption associated with the contact between the wheel and the rail is a first step towards understanding the mechanisms that deteriorate such components. This understanding will allow further reductions of the operation costs.

To such ends, this work examines the effect of three contact conditions: dry, lubricated with a commercial friction modifier and a postlubricated condition, on the energy consumption of the system at a specific section of the Metro of Medellin. The approach is made up of two mutually interactive parts: field measurement of the energy consumption of the vehicle and the friction coefficient, and simulation of the energy dissipated in the wheel/rail contact interface using multi-body simulation and the $T\gamma$ method including the spin in combination with Kalker's simplified theory [8,9].

2. Methods

2.1. Friction coefficient measurement

The coefficient of friction, COF, at the wheel/rail interface of the Metro of Medellin in line B was measured in the field using a hand-pushed tribometer, shown in Fig. 1. The friction modifier Sintono Terra HLK manufactured by Lubcom was used. According to the data sheet, it is a biodegradable ester-based friction modifier composed of aluminum–silicon, copper and molybdenum disulfide particles. Specifically, the metallic and silica particles work as friction enhancers while molybdenum disulfide particles help reducing the metal–metal contact. The measurements were performed in curve 4 between the stations San Javier – Santa Lucia in line B, where a stationary lubrication system was located.

Three friction conditions were evaluated: dry, HLK, and post-HLK. The HLK condition corresponds to the case when the measurements were performed right after the HLK friction modifier was applied on the track. The post-HLK condition relates to the measurements carried out when the supply of HLK ended but there was still a remnant layer of the friction modifier on the track. The thickness of the remnant layer was not determined quantitatively but the visual inspection of the track allowed verifying its presence. More details regarding the experimental procedure are presented elsewhere [10].

Fig. 1. Hand-pushed tribometer, TriboMetro FR-101 [10].

2.2. Energy consumption measurement

The measurements of the energy consumption were performed on board of a vehicle of the Metro of Medellín, in curve 4. The measurements were performed using a waveform recorder, WR300® from Graphtec. This device records the voltage and the current taken from the overhead lines, the time, the velocity and the location of the vehicle. Each measurement was performed twice with the same vehicle within an hour to keep a similar passenger load and weather conditions in each test.

In order to compare the energy consumption from measurements done with a slightly different velocity profile, it is proposed to subtract the kinetic power, the potential power and the drag power from the total power (see Eq. (5) below). The remaining power (P_{rest}) is dissipated in the wheel/rail contact, the bearings, the gears, the dampers, and the engines. These powers are unknown and cannot be measured. However, in P_{rest}, the largest part should be dissipated in the wheel rail contact. Moreover, all these powers depend only on the vehicle and not on the rail lubrication, with the sole exception of the contact power. It can therefore be assumed that the difference in P_{rest} between the different runs is solely due to the wheel/rail contact dissipation.

Below are the equations to calculate the powers

$$P_{tot} = I_{red} V_{red} \tag{1}$$

$$P_{kin} = mVa \tag{2}$$

$$P_{pot} = mgV(dh/dx) \tag{3}$$

$$P_{drag} = \rho_{air} A_f C_D V^3 \tag{4}$$

$$P_{rest} = P_{tot} - P_{kin} - P_{pot} - P_{drag} \tag{5}$$

where

P_{tot} : Total electric power consumed by the vehicle.
P_{kin}: Kinetic power of the vehicle.
P_{pot}: Potential power of the vehicle.
P_{drag}: Power consumed by aerodynamic drag
P_{rest}: The remaining power
I_{red}: Current consumed by the vehicle
V_{red}: Catenary voltage
Δt: Time step
m: Vehicle mass
V: Vehicle velocity
a: Vehicle acceleration
g: Acceleration of gravity on earth's surface
dh/dx: Height–distance rate
ρ_{air}: Air density, 1.09 [kg/m^3]
A_f: Frontal area of the vehicle.
C_D: Drag coefficient, 0.81.

2.3. Multi-body dynamics model

2.3.1. Vehicle model

A 3D multibody model of the railway vehicle implemented in the software package VI-Rail was developed in collaboration with the Metro of Medellin, who has provided the technical documentation and experimental results. The vehicle is comprised of three passenger