Wear 380-381 (2017) 106–114

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Prediction of top-of-rail friction control effects on rail RCF suppressed by wear

Saad Ahmed Khan [a,*], Ingemar Persson [b], Jan Lundberg [a], Christer Stenström [a]

[a] Division of Operation and Maintenance, Luleå University of Technology, Sweden
[b] AB DEsolver, Östersund, Sweden

ARTICLE INFO

Article history:
Received 31 October 2016
Received in revised form
11 March 2017
Accepted 12 March 2017
Available online 14 March 2017

Keywords:
Multi-body simulation
Wear
Rolling contact fatigue
RCF
Energy dissipation
Rail Cracks

ABSTRACT

Rolling contact fatigue (RCF) and wear, two major deterioration processes, limit the lifetime of rails. These deterioration processes are even more severe on the curves of tracks used by heavy haul trains. Because wear is a material removing process, it can suppress the formation of RCF (also known as surface initiated cracks). In railways, cracks have a higher risk of instigating a catastrophic failure than wear; hence, it is comparatively better to have wear than to have cracks. By controlling the top-of-rail friction, both of these deteriorating processes can be reduced to enhance the lifetime of rails. In order to achieve these possible advantages, the infrastructure manager of the Swedish railway is planning to implement a top-of-rail friction control technology on the iron ore line in northern Sweden wherein RCF is a major problem on the curves. The present study uses a damage index model in a multi-body simulation software and predicts the probability of RCF formation with suppressing effect of wear for different friction control values. The effect of friction control is simulated on curve radii ranging from 200 to 3000 m and axle loads ranging from 30 to 40 t at a constant train speed of 60 km/h. Findings show that on a very sharp circular curve, radius < 300 m, RCF can be eliminated without friction control due to the high wear rate. On moderate curves, 300 < radius < 1000 m, a friction coefficient (μ) of, at most, 0.3 with a Kalker's coefficient of, at most, 30% is required to avoid RCF.

1. Introduction

Until 1987, rolling contact fatigue (RCF) was not perceived as a major problem in the railway sector [1]; however, today, it is universally acknowledged as critical, particularly for heavy axle load trains [1]. RCF decreases the lifetime of the rail, and to ignore RCF is to invite catastrophe. Once a crack is generated, little energy is required to propagate it; if the depth of the crack exceeds a particular limit, the rail must be changed. A high rate of wear can remove the surface that is about to crack and even eliminate newly generated micro-cracks, but excessive wear reduces track life, making it necessary to reduce both wear and RCF.

As a form of preventive maintenance, grinding (also known as artificial wear) is conducted at regular time intervals to remove cracks. It also assists in retaining a proper cross sectional rail shape and promoting better wheel–rail contact. When the loss of rail material, due to natural or artificial wear, reaches a particular limit, the rail has to be replaced. However, both grinding and rail replacement are expensive, not only in terms of maintenance cost, but also in terms of track access time and delays affecting timetables.

Blame for higher RCF may be attributed to high speed passenger and heavy haul railways [1]. However, the pressure and creep forces between the rails and wheels cause the actual damage [2]. These creep forces depend on several variables related to track geometry, third body between rail and wheel, train dynamics, wheel–rail profiles, etc., leading to wide variations in contact area size and position.

Properly the matched wheel profile curving ability (conicity) and curving requirement can considerably reduce creep forces [3]. Moreover, the degree of utilised friction significantly affects the creep forces and, hence, wear and RCF. To control the degree of utilised friction and reduce traction forces at a particular range, a product known as a friction modifier (FM) was developed and published in 2003 [4]. FM manufacturers claim that their products provide a fixed range of friction coefficient (μ) and Kalker's coefficient on top of the rail (running surface). Kalker's coefficient takes care of the basic tendency of creepage between the rail and wheel as a function of traction forces at lower creepage levels. For the detail of creepage, refer to reference [5] and for the implication of kalker's coefficient, refer to reference [6]. Field works [6–8] and lab tests [9,10] in the USA, Canada and China have determined the

* Corresponding author.
E-mail address: saad.ahmed.khan@ltu.se (S.A. Khan).

http://dx.doi.org/10.1016/j.wear.2017.03.010
0043-1648/

benefits of using friction-control products, including the reduction of RCF, wear, corrugation, noise and fuel consumption. In contrast, Lundberg et al. [11] found that such products give unacceptably low friction and can cause long braking distance and slippage if used in large amount.

Implementation of the top-of-rail friction control (TOR-FC) technology on the Swedish part of the iron ore line (IOL) is being considered by the Swedish Transport Administration (Trafikverket). The IOL is also known as Malmbanan, a Swedish translation of IOL. It was implemented in 1903 to transport mineral ores (mainly iron ores) from Kiruna and Malmberget to sea ports in Luleå (Sweden) and Narvik (Norway). The total track length from Narvik to Luleå is 473 km. The railway line is a single track, electrified line mainly utilised by the ore freight trains operated by LKAB. Freight trains from LKAB have an axle load of 30 t, which is the heaviest in Europe. At present LKAB is attempting to increase the axle load of the trains which transport ores and trains with 32.5 t axle load are under test [13]. This railway line is the northernmost railway in Sweden and it is experiencing the problem of RCF on its curves.

Directly implementing a TOR-FC system could be expensive, because reliability of such a system is never accessed for the conditions of IOL. Simulation is a smart alternative to expensive field tests to determine the effect of friction control. This study evaluates the utility of implementing the technology using computer based simulations. More specifically, the effects of using friction control on RCF of the IOL are studied by performing dynamic multi-body simulation (MBS). Such simulations are one of the possible tools to predict the effect of friction control on wheel–rail damage. They also have the ability to analyse the life cycle cost of the rail when a friction controller is used between the wheel–rail interfaces. The present study uses a method, which combines the wear and RCF prediction method, to predict the combine effects of RCF and wear. This method was developed and validated by Burstow [14,15]. These simulations are a part of an on-going four year project, which includes both field tests and simulations. In the project, these simulations are the initial theoretical studies that used already validated method and will be compared to the field tests in later stages.

2. Methods

The simulation software used in the present study is a MBS package from GENSYS [16]. It contains mass-spring-damper physical models and geometrical equations to represent different parts of a track and a train. The package used in the present study is updated with an IOL wagon model along with the measured IOL rail and wheel profiles. To generate outputs, the MBS models the wheel–rail contact mechanics based on the Hertzian theory, in combination with the simplified theory by Kalker called FASTSIM [17], as shown in Fig. 1. The outputs from the MBS, such as creep forces, creepage, and size of the contact area, etc., are used in the prediction model, as discussed in Section 2.1. The model used in the present study is based on a combined RCF and wear prediction method, which involves the trade-off between wear and RCF. The model only predicts the chance of RCF with the suppressing effect of wear in the form of an index.

The final index depends on pressure, creep force, and creepage, etc., which are sensitive to numerous factors, including wheel–rail profile, bogie suspension, track stiffness, stiffness and damping between ground, ballast bed and rails. Because the present work focuses on the effects of friction control on wear and RCF, all the parameters except friction control values and axle loads are kept constant for all simulations. To determine the effect of FM, variations in friction coefficient and Kalker's coefficient are sufficient.

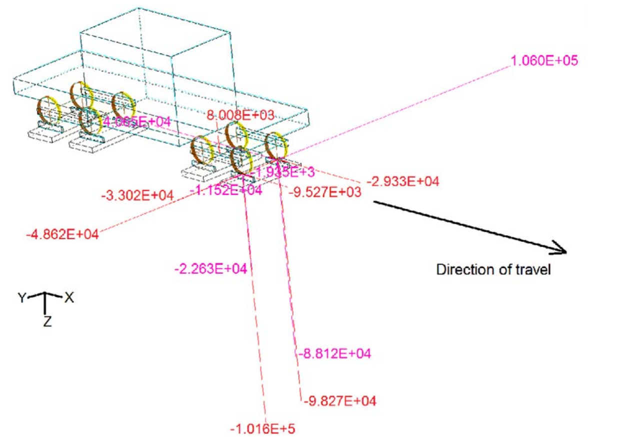

Fig. 1. Dynamic model of a wagon and a track section, showing the generated forces during a negotiation of a 200 m curve. Length of the bars represents the magnitude of the generated forces.

The influence of third body particles such as dust from the environment and different additive in the FM, e.g. anti-wear additive, is ignored. As discussed earlier, Trafikverket is planning to increase the axle load of the trains; therefore, the simulations are also performed using high axle loads. The speed of the train in the present simulations is fixed at 60 km/h, as loaded iron ore trains run at this speed and in the recent future there is no plan to change the train speed.

2.1. Damage index (DI) model

The theoretical basis of DI model is summarised as follows:

- Normal stresses and force are based on Hertzian contact theory.
- Shear stresses due to frictional forces are calculated by using Kalker's theory, Hertzian contact theory and disc-disc laboratory test.
- Wear calculations are based on energy dissipation and disc-disc laboratory tests.
- The probabilities of RCF generation are based on shakedown theory.

In general, it is well known that wear and RCF are two different processes. To obtain a realistic output, a combination of wear and RCF is required as excess wear can minimize or in some cases eliminate RCF. Burstow combines the shakedown and energy dissipation method to create a combined index method, as shown in Fig. 2. The shakedown limit, which is also sometimes known as a dynamic shakedown curve, represents the limit for generating RCF without considering the effect of wear. Energy dissipation, which is a product of creep force and creepage, is used to calculate

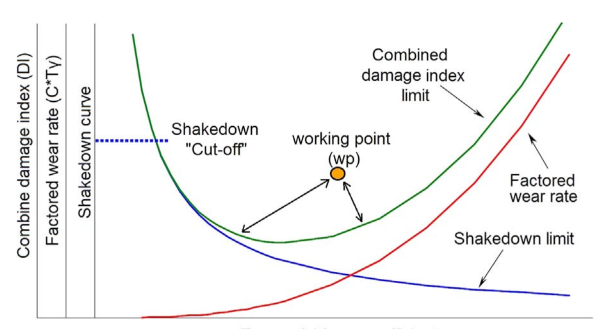

Fig. 2. Combined damage index limit based on Shakedown and factored wear rate. Adapted from [15].